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All communications should be addressed to the Editor.

No. 110. FEBRUARY, 1920. VOL. XXIV.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected in the various grades at the Council meeting on January 21st:—

Fellows (Glasgow).—Prof. A. Barr, Sir William Beardmore, Prof. J. D. Cormack, Sir John Hunter, Dr. Blackwood Murray, General J. G. Weir.

Fellows (London).—E. G. Walker, L. F. Plugge, R. H. Mayo.

Associate Fellows (London).—A. Knight Croad, A. W. Holden, R. E. Russell, O. S. Stiles, F. J. Tippen.

Associate Fellows (Glasgow).—The Hon. Alan Boyle, Sir John Reid, Hugh Reid.

Members (London).—H. Leitner.

Associate Members (London).—J. S. Lindsay, J. R. Maher, S. R. M. Naidu, J. Reid, R. E. Smith, E. J. Stuppen, J. W. P. Uren.

Associate Members (Glasgow).—C. M. Mortimer.

Foreign Members (London).—Melvin Hall, Augustus Post.

R.A.F. Memorial Fund.

Details will be found on another page of a fund which is being raised to provide a Royal Air Force Memorial. The Council feel that this is a matter on which united action is desirable, and therefore invite members to forward subscriptions to the Secretary on or before February 29th. Cheques should be made payable to "Aerial Science, Ltd.—R.A.F. Memorial Fund."

Lecture Syllabus.

The following syllabus of lectures has been arranged for the remainder of the present session:—

Wednesday, January 21st.—"The Principles of Rigid Airship Construction," by A. P. Cole, R.C.N.C., A.M.Inst.N.A. The chair to be taken by Wing Commander T. R. Cave-Browne-Cave, C.B.E., Fellow.

Wednesday, February 4th.—"Rigid Airships and their Development," by Squadron Leader J. E. M. Pritchard, O.B.E. The chair to be taken by Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C., Associate Fellow.

Wednesday, February 18th.—" Aircraft Design in Relation to Standardisation," by Major Percy Bishop, Associate Fellow. Chair to be taken by H. White Smith.

Wednesday, March 3rd.—" Flying Over Clouds in Relation to Commercial Aeronautics," by Professor B. Melville Jones, Associate Fellow. Chair to be taken by Lieut.-Col. H. T. Tizard, Fellow.

Wednesday, March 17th.—" Airship Machinery, Past Experience and Future Requirements," by Major C. F. Abell, O.B.E., Associate Fellow. Chair to be taken by

Wednesday, April 14th.—To be announced later.

Wednesday, April 28th.—" Trans-Continental Flying," by Capt. P. D. Acland. Chair to be taken by

Wednesday May 12th.—" A Comparison of the Cost of Air Ton-Miles with other Forms of Transport," by Brig.-Gen. Lord Montagu of Beaulieu, C.S.I., V.D., D.L., M.P. Chair to be taken by

Wednesday, May 26th.—" Some Points of Importance in the Work of the Advisory Committee for Aeronautics," by Sir Richard Glazebrook, K.C.B., F.R.S., Fellow. Chair to be taken by

Wednesday, June 9th.—" Wilbur Wright " Lecture, by Commander Hunsaker, U.S.N. Details to be announced later.

It is desired to urge upon members that the discussions following upon the lectures should be of considerable importance and interest. It has, however, been noticed that those who are qualified to join in the discussion frequently do not attend the lectures, or, if present, show a reluctance to speak. It is felt that only by a full representative discussion can the full benefits result and members are therefore urged to attend lectures on subjects in which they are interested and take part in the discussion afterwards. Advance copies of each paper can be obtained by those intending to speak, on application to the Secretary. Prior notice of an intention to speak is an assistance to those organising the meeting, though not a necessary preliminary.

Students.

Attention is called to the fact that membership of the Student grade is only open to those under the age of 26 who are studying at a recognised technical institute or college. Any student who has attained the age of 26 should apply to the Secretary for election as Associate Fellow or for transference to the non-technical grade of Member.

Weekly Notices.

It has now been arranged for weekly notices of matters of interest to members to be inserted in " Flight," " Aeronautics," the " Aeroplane," " Aeronautical Engineering," the " Automobile Engineer " and the " Times."

Arrangements for the Month.

February 11th (*Scottish Branch*).—Lecture by the Chairman on " Safety in Flight " at Glasgow.

February 12th (*Scottish Branch*).—Chairman's lecture in Edinburgh.

February 13th (*Scottish Branch*).—Chairman's lecture in Dundee.

February 17th, 4.0 p.m.—Publications' Committee Meeting.

February 17th, 5.0 p.m.—Council Meeting.

February 18th, 8.0 p.m.—Lecture by Major Bishop, " Aircraft Design in Relation to Standardisation."

February 25th, 5.0 p.m.—Technical Terms Committee Meeting.

W. LOCKWOOD MARSH,
Secretary.

PROCEEDINGS.

FOURTH MEETING, 55th SESSION.

The Fourth Meeting of the Fifty-fifth Session was held in the Hall of the Royal Society of Arts, London, on Wednesday, December 10th, 1919, Lieutenant-Colonel Mervyn O'Gorman occupying the chair.

Mr. JOHN D. NORTH, F.R.Aë.S., F.R.Met.Soc., delivered the following lecture:—

AIRCRAFT UNDERCARRIAGES.

The undercarriage is described in the Society's Glossary as "That part of the aircraft beneath the body intended for its support on land or water and to absorb shock on alighting."

It is my intention to confine my remarks in this paper to undercarriages designed to support aircraft on land, that is to say, colloquially, "landing gears." The reasons for this limitation are obvious; it is scarcely possible to compare even in a general manner the undercarriage problem of the land machine and the seaplane, and in the latter case the already wide subject has to be extended to consider float design.

The historical development of the undercarriage shows well-defined phases reflecting the performances and functions of the complete aircraft. In the early Wright machines, which were provided with a launching gear, the problem of alighting only required to be considered. The light weight and slow landing speed of the aeroplane demanded but slight shock absorbing capacity and long skids only were fitted to bridge inequalities in the ground.

Contemporaneously in France and in this country attempts were being made to fly without launching gears. As the amount of time spent in taxi-ing, or "rolling" as it used to be called, represented a very large proportion of the total "flying" time, the undercarriages were designed to meet these conditions. The outstanding feature was the extensive use of swivelling forks carrying the wheels, the erratic course of the machine in its frantic efforts to rise requiring a liberal measure of tracking. As these machines frequently suffered disaster, being upset by running into ditches and so forth, the idea of combining the wheel and skid was materialised in the Henri Farman undercarriage. This had very long skids, each provided with two wheels mounted on a common axle and sprung to the skid with rubber. This system was extensively adopted, but as the performance of machines improved the skid gradually became shorter and shorter till in the well-known and almost universal "Vee" type undercarriage it disappeared altogether. At the same time the arrangements of springs and radius rods provided in the original Farman also died out. It is perhaps interesting to recall that the "Vee" undercarriage was extensively condemned on its appearance as highly dangerous.

Figure 1 shows diagrammatically the process of development culminating in the "Vee" type undercarriage.

By a similar process of development the wide-track Farman chassis developed into the typical undercarriage of the twin engine machine exemplified by the Vickers Vimy and the Handley Page, while in a different form it appears with two wheels only in the B.A.T. and the Boulton and Paul Bourges (Fig. 2).

The most notable departures from these types originated in the Breguet Oleo gear, which is shown developing into the R.E.7 and F.E.2C. Oleo gears. The undercarriage of the Avro tuition machine may be traced to the early single wheel R.E.P. (Fig. 3).

I hasten to add that I do not suggest that all designs subsequent to the original type were plagiarisms, but rather that they represent natural lines of development.

Of the final types found in general use there is no doubt that the " Vee " holds the field by sheer weight of numbers and the reason for this is not far to seek. The development of aircraft has been almost exclusively military for the last five years and, in considering the safety and utility of an aeroplane, danger from enemy action was an important item.

By cutting down the resistance of the undercarriage to a minimum a definite improvement in performance was obtained and the consequent added security in action more than compensated for any increased difficulty or danger in landing.

The use of the " Vee " gear has been principally confined to the smaller types of aircraft, but it must be realised that the large craft were in an elementary stage compared with their smaller sisters, and it is difficult to find a case of a large machine whose performance was in itself, or could by reducing undercarriage resistance be made to be, a protection against enemy action.

Where aircraft are to be used for civil purposes, or where military aircraft are required in peace to have a longer term of life than in war, improvements in undercarriages would seem to be an essential part of their development. There is little doubt that the shock absorbing capacity can be greatly increased and at the same time provision made for landings side to wind or with the machine canted or tilted.

The shock absorbing capacity of an undercarriage depends on the total forces that the structure will stand without failure, and also the amount of travel of the shock absorbing gear. We may first consider the most elementary form of undercarriage, *i.e.*, pneumatic tyred wheels mounted on a rigid axle (Fig. 4).

The machine has a vertical component of velocity u when the wheel touches the ground and, as we are only considering the machine being brought to rest in the vertical plane, we may take the kinetic energy as $mu^2/2g$ (foot-pound units).

The force P on the tyre is a function of the tyre deflection (x), hence total energy absorbed by the tyre is

$$\int_0^a F(x)\,dx$$

where a is the deflection when P has reached the maximum permissible load. Hence the limiting vertical velocity is given by

$$u^2 = \frac{2g}{m}\int_0^a F(x)\,dx$$

Figure 5 shows an experimental curve for $P = F(x)$. The values of the deflection with diminishing load are not the same as those with increasing load. Consequently the vertical velocity after the tyre has again expanded (u_1) is given by

$$u_1^2 = \frac{2g}{m}\int_0^a F(x)\,dx$$

The area of the hysteresis loop represents the energy dissipated in heat. In composite structures such as tyres the dissipated energy may possibly be partly accounted for in other ways, but it is not necessary to consider this in detail here.

The aeroplane, rebounding with a vertical velocity u_1, will leave the ground and strike it again with a velocity u_2. It is obvious that $u > u_1 > u_2 \ldots > u_n$, etc., and the C.G. of the machine gradually comes to rest in the vertical plane.

Before considering the variations in shock absorbing effect arising from different forms of landing gear, we may first discuss the permissible values of P or rather the ratio P/W (W being the weight of the aeroplane). This is usually termed the load factor.

The value of this factor will be influenced by the structure of the aeroplane as designed for flight. It may be accepted that machines are designed with flight load factors of 8 to 4 according to type. That is to say, they are designed to withstand the stresses arising from steady flight, supposing g to be increased to $8g$ or $4g$. It is essential, therefore, if the structure weight of the aeroplane is to be kept low, that the greatest advantage should be taken of the "flight" structure and that the added weight to withstand landing loads should be a minimum.

Consider first a tractor aeroplane with "Vee" type undercarriage.

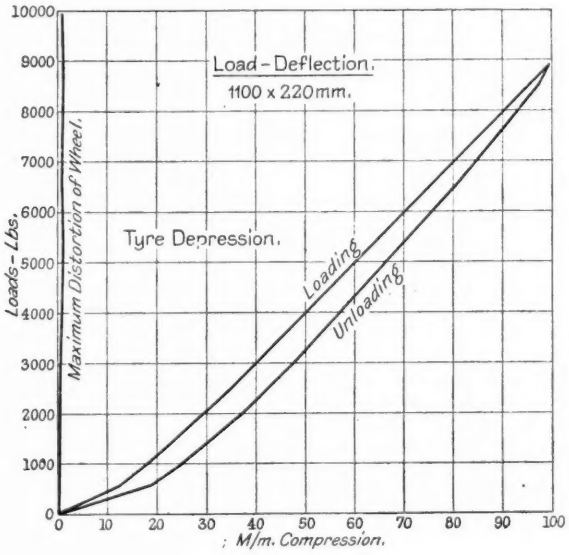


FIG. 5.

The principal vertical forces acting on the machine in flight are shown in the accompanying figures (Figs. 6 and 7). They are similarly shown for two extreme cases of landing—(1) C.G. over wheel, (2) wheel and skid touching ground simultaneously.

It will be seen from the stress diagrams that an "undercarriage" load factor of the same order as the "flight" factor is an economical value. In the case of an undercarriage mounted on the planes this is even more obvious.

The weight of structure to take the down loads on the wings is unimportant. The maximum tail skid load (with the chosen factor) is often of the same order as the maximum down load on the tail and of the opposite sign, hence the rear part of the fuselage can economically be made symmetrical (structurally if not geometrically). The load on the tail skid is determined by the position of the wheels in relation to the C.G. when the machine is at rest on the ground. It is obviously desirable that the incidence of the main planes with the tail skid on the ground should approximately correspond to the angle of maximum lift for the

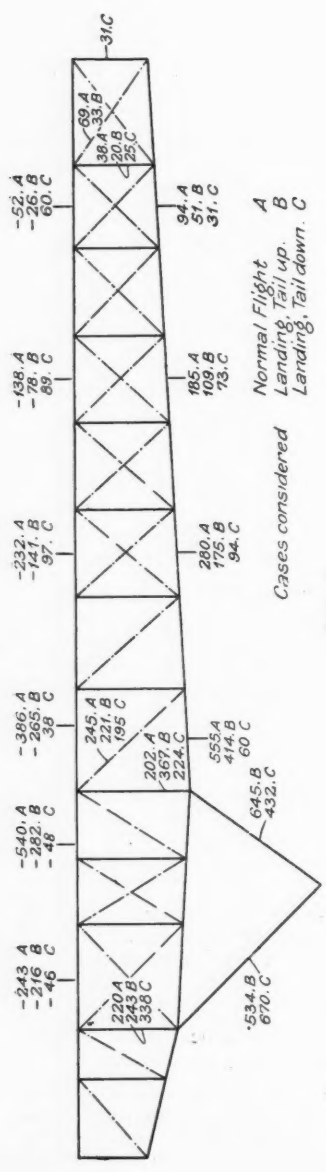
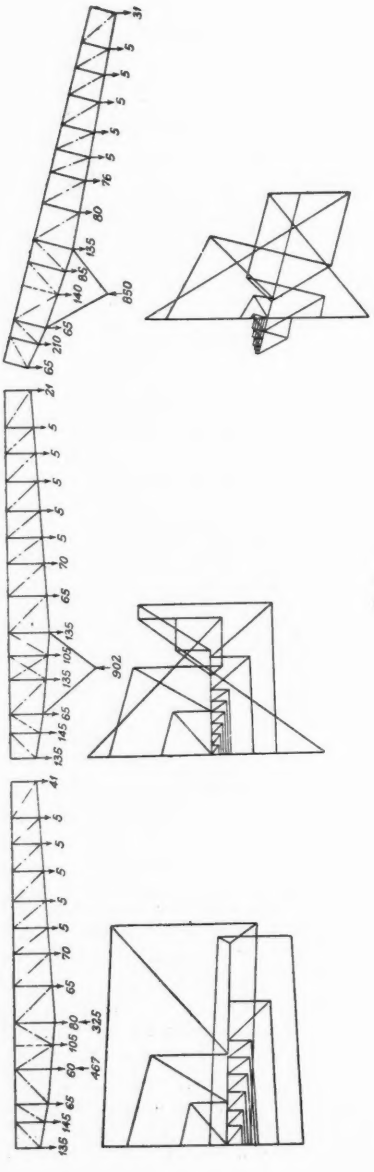

-243. A
-216. B
-46. C
-540. A
-282. B
-48. C
-386. A
-265. B
-38. C
-232. A
-141. B
-97. C
-138. A
-78. B
-89. C
-52. A
-26. B
-60. C
220. A
243. B
338. C
534. B
670. C
645. B
432. C
555. A
414. B
60. C
202. A
367. B
224. C
245. A
221. B
195. C
280. A
176. B
94. C
185. A
109. B
73. C
94. A
51. B
31. C
69. A
38. A
33. B
20. B
25. C
31. C
Cases considered
Normal Flight A
Landing, Tail up. B
Landing, Tail down. C

FIG. 6.


31
5
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140 65
850
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135 105
135
902
135 145 65
41
5
5
5
5
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5
70
65
105 80
60
467
325
135 145 65

FIG. 7.

planes (say 14°). At the same time, to prevent the machine from turning over on its nose, the angle between the line passing through the C.G. and the point of contact of the wheels and ground and the vertical (the thrust line being taken horizontal) should not be less than a minimum angle δ. The ratio of load on tail skid to load on wheels will then be given by

$$\frac{\text{Weight on skid}}{\text{Weight on wheels}} = \tan(\beta + \delta)\tan(\beta + \epsilon)$$

where δ is defined above.

β is the angle the thrust line makes with the horizontal when the skid is on the ground.

ϵ is the angle between the line joining the skid to the C.G. and the thrust line.

As it is desirable to keep the load on the tail skid down δ should be as small as is safely possible. At the same time it is obvious that a high value of δ will produce a big moment causing the machine to "buck" in getting off and landing.

An average taken from a large number of machines seems to show that 12° is a suitable value for δ.

The considerations briefly outlined above enable us to arrive at the maximum permissible loads on the wheels and skids.

Since the loads on the undercarriage are fixed, the definite requirements of the shock absorbing gear may be arrived at by choosing a value for u. Exactly what this value should be is a controversial matter on which I hope to hear opinions expressed in the discussion. In any case it seems reasonable to state that it should be a function of the minimum value of $V \sin\gamma$ (gliding angle) in steady flight, engine off. In other words, if $u = V \sin\gamma$ the machine would just collapse if it struck the ground gliding without flattening out. Of course, in a good landing u is reduced at the expense of the kinetic energy of the machine.

It would appear that for machines with fairly high loadings (*e.g.*, 8-9 lbs/sq. ft.) a value for u of about 15 ft./sec., which just corresponds with the minimum value of $V \sin\gamma$, is as much as may be expected. For a good undercarriage the permissible deflection or "travel" usually depends on the geometry of the machine, and consequently in big machines it should be possible to design for higher values of u. At the same time the "flight factor" is usually lower on large aeroplanes which will tend to limit the improvement in shock absorbing capacity due to increased deflection.

Supposing now that a value for u has been arrived at we can turn to the details of the shock absorbing mechanism.

Considering the problem with increasing degrees of complexity we get

(1) Wheels and tyres.
(2) ,, ,, and springs.
(3) ,, ,, ,, and Oleo gear.

Fortunately, so far as wheels and tyres are concerned, we are in possession of a fair amount of experimental data. The Palmer Cord Tyre Company, who furnish almost exclusively the wheels and tyres used on British aeroplanes, have carried out extensive researches to aid their designs, and it is gratifying to those who appreciate the value of research to note the success which has resulted from their efforts.

Tyres.

Construction.

Palmer cord aero tyres and rims are specially designed to withstand very severe lateral stress.

The ordinary beaded edge tyre of the type used for cycles and motor cars has been found to give trouble when used for aeroplanes, because, when landing with a side wind blowing, the lateral stress set up in the tyre causes the "toe" of the tyre bead to lift, which allows the air tube to blow underneath and burst, or in some cases the tyre is pulled bodily off the rim.

For Palmer aero tyres a rim of special design is used, and the beads of the cover are so constructed that they lock in the rim and are thus capable of withstanding a very great lateral stress without either pulling out of the rim or "lifting" at the toe of the bead.

The rubber impregnated cord fabric is laid across the tyre connecting steel hooks in the bead. Alternate layers of cord and rubber form the tyre (Fig. 8). The effect of this construction on the behaviour of the tyre under side load is shown in Fig. 9. The inflation pressure is important, an average of 50 lbs. per sq. inch being employed. Only a slight rise in pressure takes place under load.

The machine for testing a wheel and tyre under combined direct and side loads is shown in Figs. 10, 1 and 2. The deformation of the tyre is here illustrated.

The following is a comparative list of the more usual sizes with their weights —complete with wheel and shield—and their safe load, carrying a factor of safety approximately 5 :—

Tyre.	Weight.	Safe load (lbs.).
600 × 75 mm.	12 lbs. 3 oz.	1000
700 × 75 mm.	14 ,, 14 ,,	1100
700 × 100 mm.	21 ,, 6 ,,	1600
750 × 125 mm.	23 ,, 8 ,,	1800
800 × 150 mm.	28 ,, 2 ,,	2200
900 × 200 mm.	53 ,, 0 ,,	4000
1100 × 220 mm.	81 ,, 0 ,,	5000
1250 × 250 mm.	114 ,, 0 ,,	6000
1500 × 300 mm.	145 ,, 0 ,,	8000
1750 × 300 mm.	194 ,, 0 ,,	9000

The loads given for all wheels up to and including 900 × 200 mm. are the results of actual testing. Beyond this size the loads are calculated.

The permissible normal loads on wheels are often determined by ground conditions. The formula W = tread″ × dia.″ × 12 is generally employed to check for bearing pressure. In the event of abnormally soft ground special square treads are used (Fig. 11).

The wheels are tested in a special machine and the deflections due to given loads are noted (Figs. 12 and 13). In Fig. 5, giving deflection against load for a 1,100 × 220 mm. wheel, there is also given the deflection of the wheel; this is obviously so small that it can be safely neglected and has been omitted in the other cases (Fig. 14).

On unloading, the load deflection curve falls below that obtained on loading; the area between the curves is a measure of the work dissipated. This, in the case of "static" loading, is of the order of 8 per cent. of the total work.

Fig. 15 gives the area of contact for the same four wheels under varying load.

In all these cases the load has been applied and taken off gradually, but when it is applied suddenly—and in actual practice on aeroplanes this is always so—there may be, and investigation has shown there is, considerable difference.

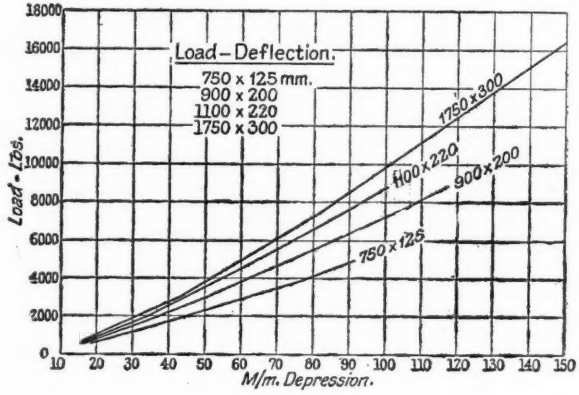

FIG. 14.

The Palmer Tyre Company have kindly carried out, at my request, a number of tests on a 750 × 125 mm. wheel both with gradual and sudden loading.

For the sudden loading the wheel was weighted till the total weight was

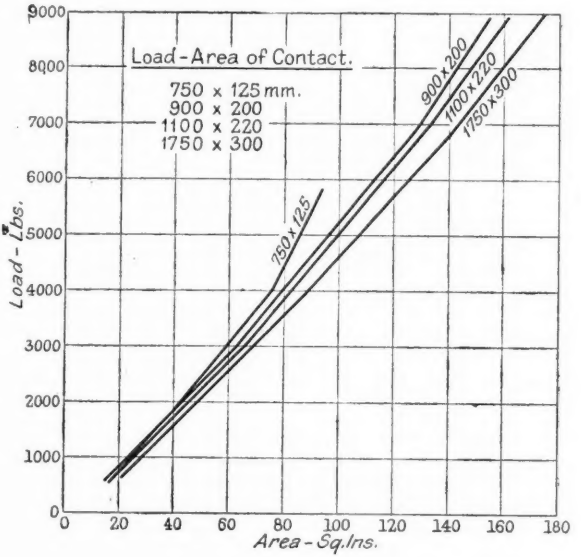

FIG. 15.

150.5 lbs. and placed in the bouncing wheel testing machine (Fig. 16). From a known height the weighted wheel is dropped and the area of contact is obtained by means of a trace on an absorbent pad (Fig. 17). The height to which the

wheel bounces is noted. The depression of the tyre is obtained from a knowledge of the area of contact (Fig. 18).

If h, h' and k feet are respectively the dropped height, the rebound height and the depression, then the energy stored in the tyre when most depressed is given by

$$150.5\ (h + k) \text{ foot pounds}$$

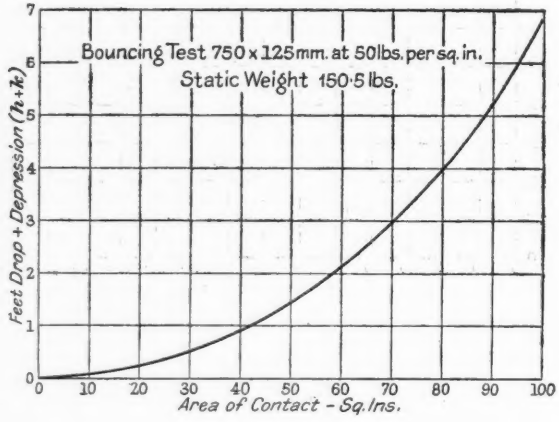

FIG. 17.

and the energy on the rebound

$$150.5\ (h' + k) \text{ foot pounds.}$$

The hysteresis is

$$150.5\ (h - h') \text{ foot pounds,}$$

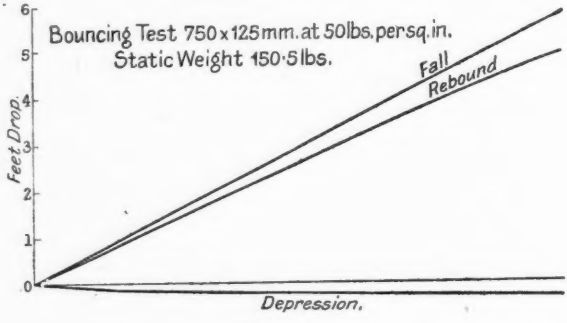

FIG. 18.

which expressed (Fig. 19) as a percentage of the original energy is

$$\frac{h - h'}{h + k} \times 100\%$$

The results obtained are tabulated below

h ft.	k ft.	Energy taken up. ft. lbs.	Energy given up on rebound. ft. lbs.	Energy dissipated. ft. lbs.	Energy dissipated. per cent.
1	0.15	172.5	133.3	39.2	22.7
2	0.20	330.9	264.2	66.7	20.1
3	0.24	487.5	396.7	90.8	18.6
4	0.28	643.3	526.7	116.6	18.1
5	0.31	800.0	656.7	143.3	17.9
6	0.34	954.2	768.3	185.9	19.5

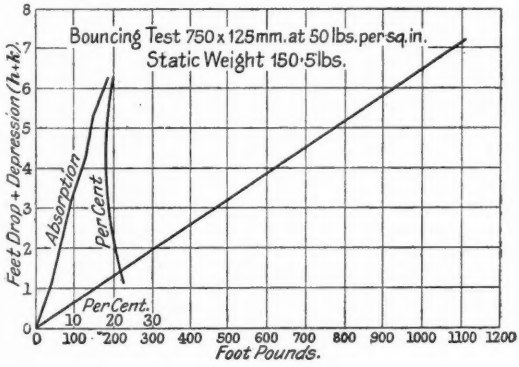
Bouncing Test 750 x 125 mm. at 50 lbs. per sq. in.
Static Weight 150·5 lbs.
Feet Drop + Depression (h+k)
Absorption
Per Cent.
Per Cent.
10 20 30
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
Foot Pounds.

FIG. 19.

A similar wheel was next subjected to "static" loading and the same depressions of the tyres obtained. The results are tabulated below:—

k ft.	Load. lbs.	Energy taken up. ft. lbs.	Energy given up. ft. lbs.	Energy dissipated. ft. lbs.	Energy dissipated. per cent.
0.15	2110	125	—	—	—
0.20	3100	250	230.8	19.2	7.7
0.24	3790	385	355.8	29.2	7.6
0.28	4500	550	507.5	42.5	7.7
0.31	5250	724.2	669.2	55.0	7.6
0.34	5800	904.2	830.8	73.4	8.1

The most interesting points in a comparison of the two series of tests are, firstly, that in the "dynamic" tests for a given tyre depression more energy is absorbed than in the "static" case, and secondly, a higher percentage of the energy is dissipated (Fig. 20).

The former of these results agrees in principle with results given in C.I.M. 744 and also quantitatively for the smaller depressions. On a number of wheels of varying size and varying internal pressures the load required to depress the tyre completely, and hence the energy taken up by the tyre, was determined. To obtain the same depression by dropping a heavy weight on the tyre another set of figures for the energy was obtained. Comparing the two it was found that with sufficient accuracy the energy absorbed in the "static" test was 70 per cent. of that in the "dynamic." In the figures given above (Palmer tests) this rises from 72 per cent. for the one-foot drop to 95 per cent. for the six-foot drop.

Before leaving the tyre question it is interesting to note the extreme range covered by the Palmer aero wheels and tyres. This is well illustrated in Fig. 21.

Axle.

The axle on which the wheels are mounted is itself capable of absorbing a certain amount of shock, but even in extreme cases this does not exceed 8 per cent. of the total kinetic energy of the machine and has been neglected in most of the work that follows.

A general uniformity of axle design has now been arrived at. The Air Board specification usually demanded for axles is either T.2 or T.14. T.2 is a nickel-chrome steel having an ultimate tensile strength of not less than 85 tons

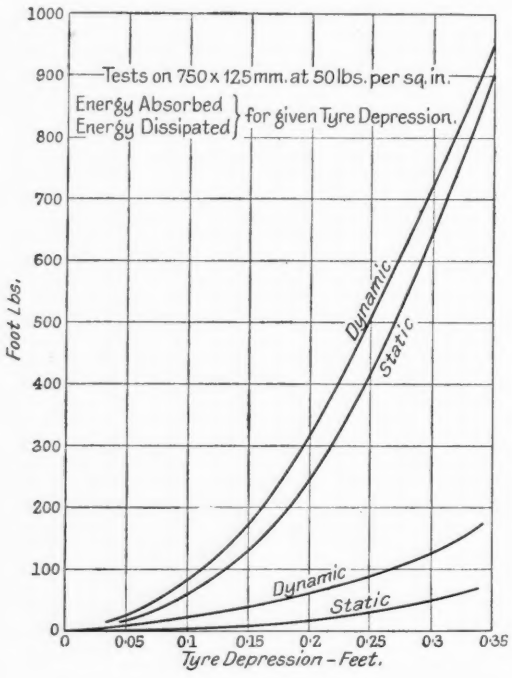

FIG. 20.

per sq. in. T.14 is a tempered carbon steel, the U.T.S. being rather lower than for T.2.

Since axles are not called upon to sustain bending moments of the same magnitude in all planes it is not certain that the circular steel tube represents the last word in axle design, particularly in very large machines. Some developments in beams manufactured from steel strip may perhaps be applied to axles, but the subject is too wide and too controversial to be considered here.

Wheels, Tyres and Springs.

The undercarriage in which the shock absorbing is confined to the tyres is a comparative rarity and the axle is commonly sprung, usually with rubber, to the remainder of the structure. Steel springs can easily be shown to be heavier

than rubber, and as the principles governing the design of steel springs are common engineering knowledge they need not be discussed.

A comparison made between a German made steel spring and British made rubber showed that the latter had the advantage in both weight and shock absorbing capacity. (See C.I.M. 743.)

As a matter of almost universal practice the rubber shock absorber consists of a number of strands of rubber held in an initial state of strain and protected by flexible linen braid. This braid has an important influence on the load extension diagrams.

Of the two forms of rubber shock absorbers there seems little doubt that the better is that of a number of rings.

In the first place, tests show that the shock absorber in the form of a ring is more reliable than in the length since all the materials are under better control during manufacture. The tensile strength of a 20-yard coil generally varies considerably at different positions of its length and no precautions taken in manufacture will materially reduce this variation, whereas 20 rings each of a yard mean circumference, made under the same conditions, will give far more uniform results.

Secondly, it is very improbable that the initial tension on a straight cord, wrapped round by hand power, will be the same in each lap. In the case of a number of rings a uniform initial tension is fairly readily and accurately obtained.

Messrs. Luke Turner and Co., of Leicester, have made some interesting discoveries in their researches on the best form of rubber shock absorber. They say:—In the case of a ring, if thoroughly wetted when under a load sufficient to produce about 50 per cent. extension, it will be found to have a permanent extension of 8 per cent. measured on the straight length, but it returns to its original dimensions as the moisture evaporates. To obtain a uniform initial tension on each ring the internal diameter should be calculated from the minimum position of the spools and 8 per cent. deducted from the circumference. The ring is then made to this internal diameter, saturated with water when under tension and then placed on the spools in a wet condition. When dry the initial tension will correspond with the load required to produce an 8 per cent. extension, which load can easily be found by a static test on the ring when in a dry condition. Mr. Turner hopes in the near future to improve on this by treating the ring so that it retains the 8 per cent. extension, and when required for use it will be immersed in some liquid solution which will allow it to shrink when on the spools. This method, if successful, will be very convenient for spare rings for renewals.

Their test results show in the case of a ring the energy absorbed in hysteresis is a larger percentage of the total energy than in the case of the ordinary cord. In a ring it varies from 15 to 20 per cent.

These hysteresis figures have been obtained by static tests, *i.e.*, the load gradually increased or decreased. On the other hand, the few experiments that have been made with rapidly alternating loads seem to indicate that the hysteresis energy shrinks to a very small percentage of the total, both for the ring and ordinary cord. As a rapidly alternating load represents the condition when an aeroplane lands it would seem that it is doubtful whether rubber, either as ring or cord, will act as a shock dissipater.

(Fig. 22.) The effect of repetition of loading is very marked. Messrs. Turner have investigated the effect of repeated application of load to produce 66 per cent. extension.

After 10,000 repetitions the energy absorbed in stretching to 66 per cent. has fallen off nearly 23 per cent. whilst the hysteresis expressed as a fraction of the

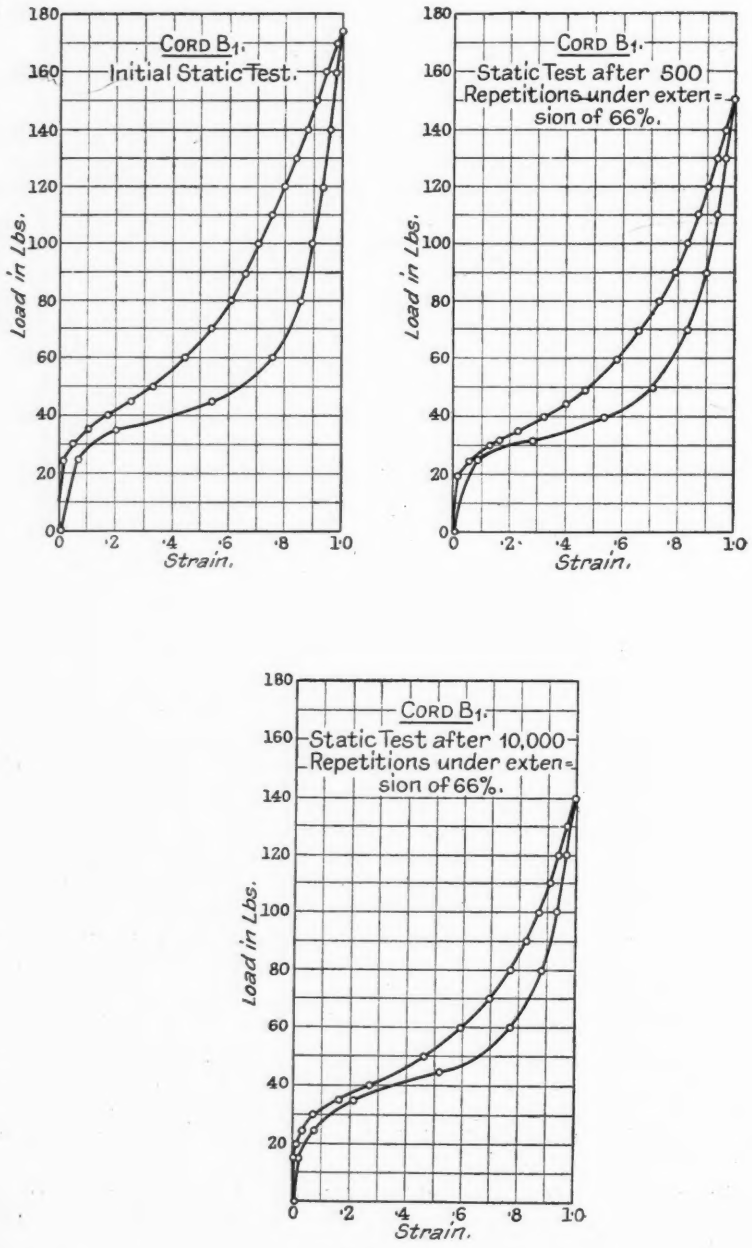
Cord B1.
Initial Static Test.
Load in Lbs.
Strain.
Cord B1.
Static Test after 500 Repetitions under extension of 66%.
Load in Lbs.
Strain.
Cord B1.
Static Test after 10,000 Repetitions under extension of 66%.
Load in Lbs.
Strain.

FIG. 22.

energy expended has fallen off from 32 per cent. to 17½ per cent. The figures in the repetition tests are as under:—

	Work done in stretching 66%.	Hysteresis.	% hysteresis.
Initial test	79.0	25.3	32.0
After 500 repetitions ...	62.5	15.0	24.0
After 10,000 repetitions ...	61.0	10.6	17.4

Experiments carried out by Boulton and Paul show that with a ten-inch ring subjected gradually to a load of half a ton the hysteresis, if the time taken to apply the load is half a minute, is less than a fifth of that when the time taken is four minutes (Fig. 23).

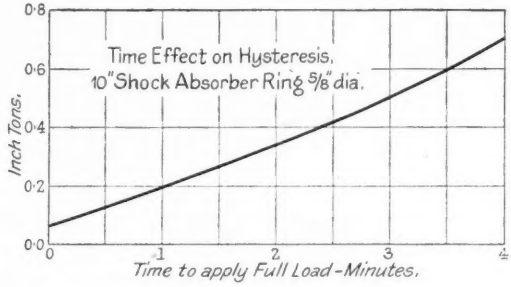

FIG. 23.

A ten inch rubber shock absorber ring $\frac{5}{8}$in. diameter was attached to hooks in the testing machine and a load of half a ton applied at different rates.

The time taken for the full load to be exerted was ½, 1, 2½, 3 and 4 minutes.

In each case a number of observations of the extensions corresponding to different fractions of the full load were noted, from which a series of hysteresis curves were plotted.

The areas enclosed by these curves were determined and plotted on a rate of loading base. The curve drawn approximately through the points gives at once the effect of changing the rate of applying the load.

In the case of an undercarriage fitted with pneumatic tyres and rubber shock absorber a sufficiently near approximation for the shock absorbing capacity may be arrived at by plotting the load deflection curve of the rubber shock absorber and tyres, and integrating with the maximum permissible load as superior limit. More accurately the kinetic energy of the wheels and tyres and axle may be considered separately (since it does not affect the springs) and account may be taken of axle deflection. In most cases however the approximation suggested is sufficiently accurate and has the advantage of being extremely easy.

Oleo Gear. Fig. 23 (2).

In its simplest form the oleo gear consists of a piston (A) of circular cross section which can move in a cylinder (B) against a resistance. This resistance is provided by oil, which as the piston advances is forced through some small orifices (C) in the piston head with a very high velocity.

If A = effective area of piston head, *i.e.*, total area less area of orifices.
a = effective area of orifices.
l = length of orifice.
m = hydraulic mean depth of orifice = area of orifice/perimeter.

V = velocity of piston.
v = velocity of liquid through the orifices.
F = frictional coefficient due chiefly to the surface of the orifices.
ρ = density of liquid.
p = excess pressure behind the orifices in lbs.

We have

$$p/\rho = (1 + Fl/m)\, v^2/2g$$

(See Gibson on "Hydraulics and its Applications.")

For continuity of liquid flow

$$AV = av$$

and therefore

$$p/\rho = V^2/2g \;.\; (1 + Fl/m)\, A^2/a^2 \quad . \quad . \quad . \quad . \quad (1)$$

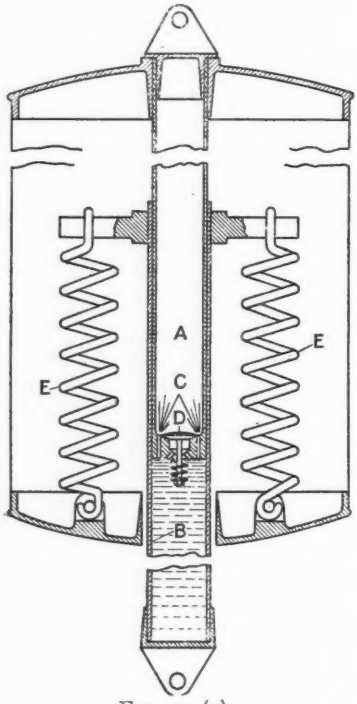

FIG. 23 (2).

Total resistance

$$pA = \rho V^2/2g \;.\; A^3/a^2 \;.\; (1 + Fl/m)\, kV^2.$$

If W is the weight of an aeroplane with oleo gear on either wheel of a two-wheeled undercarriage it follows that

$$2kV^2 = -W\frac{dV}{dt} = -WV\frac{dV}{dx}$$

$$\therefore \frac{2k}{W}dx = -\frac{dV}{V}$$

For a movement x of the piston head with a fall off in velocity from V_0 to V_1 we have, integrating the last equation

$$\frac{2k}{W} \cdot x = \log_e \frac{V_0}{V_1}$$

or

$$V_1 = V_0 e^{-2k/W \cdot x} \quad . \quad . \quad . \quad . \quad (2)$$

This equation gives the velocity at any time in terms of the original velocity and the piston travel.

The pressure p may however rise to a value considerably higher than is convenient. In the case of a simple oleo a valve may be provided, set so that whatever the vertical velocity the load on the piston will not be sufficient to break the aeroplane though of course there is no guarantee that with high velocity all the kinetic energy of the machine will be absorbed. If no valve is fitted there is a definite limiting velocity above which the forces set up on the gear can no longer be sustained by the aeroplane. A valve (D) is therefore set in the piston head, which opens as soon as p rises above a value previously determined upon. By this arrangement the maximum pressure on the sides of the cylinder and on the piston head is known and the gear can be made just strong enough to stand this pressure.

Until the valve closes the retardation is constant and given by

$$2\pi A = -WV\frac{dV}{dx}$$

where π is the pressure at which the valve opens.

The value of V when the valve closes is given by

$$\pi A = kV^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and when the valve closes the equation (2) holds providing V_0 has the value determined in equation (3).

The next stage in the development of the oleo gear is that the free movement of the piston, besides being retarded by the oil, is further retarded by some spring device shown diagrammatically at (E). In an aeroplane this resistance is generally provided by the extension of elastic.

If T_e is the tension in the elastic at any stage, the rate of retardation is given by

$$T_e + 2kV^2 = -W\frac{dV}{dt} = -WV\frac{dV}{dx}$$

In practice this equation is not as a rule amenable to mathematical treatment and the slowing up of the aeroplane is best done by step by step integration.

When however the oleo gear is fitted with a valve to keep the pressure in the cylinder below a certain value, an approximate value for the total distance travelled by the piston before the energy of the aeroplane is absorbed can be obtained in the manner shown in the following example. (No further extension of the general case can be given.)

For a particular design of oleo gear

$$\frac{A}{a} = 108$$

$$A = 3.98 \text{ sq. in.}$$

$$F = 0.005 \text{ (see Gibson on "Hydraulics")}$$

$$l = \frac{1}{12} \text{ ft.}$$

$$m = \frac{1}{384}$$

$$\frac{Fl}{m} = 0.16$$

$$\rho = 62.4$$

With these values

$$p = 91\ V^2$$
$$k = 362$$

The weight of the aeroplane is 7,500 lbs.

and so $V = V_0 \times 10^{-0.1125\,x}$ where x is now in inches,
$\pi = 91\ V_1^2$

where V_1 is downward velocity of the aeroplane when the valve closes.

The pressure after a distance of travel x inches after the valve closes is given by

$$p = 91\ V^2$$
$$= 91\ V_1^2 \times 10^{-0.225\,x}$$

and the total pressure $= pA = 362\ V_1^2 \times 10^{-0.225\,x}$.

The work done in travelling this distance x inches

$$= \int_0^x 362\ V_1^2 \times 10^{-0.225\,x}\,dx$$

$$= 3.98\,\pi\ 1.93\,(1 - 10^{-0.225\,x}) \text{ inch pounds} \quad . \quad . \quad . \quad (4)$$

The function $1.93\,(1 - 10^{-0.225\,x})$ has been plotted against x and with the help of the graph it is simple to find the work done for any distance of travel x up to 8 inches after the valve closes (Fig. 24).

The work done in the oleo with constant total pressure $3.98\,\pi$ over a distance of travel of y inches with constant $p = \pi$ is

$$3.98\,\pi y \text{ inch lbs.}$$

(Fig. 25.) If E_y represents the work done in extending the elastic y inches beyond its original extension, the total work done, for each leg, is

$$E_y + 3.98\,\pi y \text{ inch lbs.}$$

The energy lost by the aeroplane is

$$\tfrac{1}{2} \times \frac{W}{g}(V_0^2 - V_1^2) \times 12 \text{ inch lbs.}$$

$$\therefore\ E_y + 3.98\,\pi y = 3W/g\ .\ (V_0^2 - \pi/91)$$

$$\text{or } \pi = \frac{699\ V_0^2 - E_y}{3.98\,y + 7.68} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

π has been plotted against y for a range from 0 to 9 for values of V_0:—12, 10, 8, 6, 4 (Fig. 26). From the graph it is possible to find the value of y corresponding to any value of π up to 5,000 lbs. per sq. in.

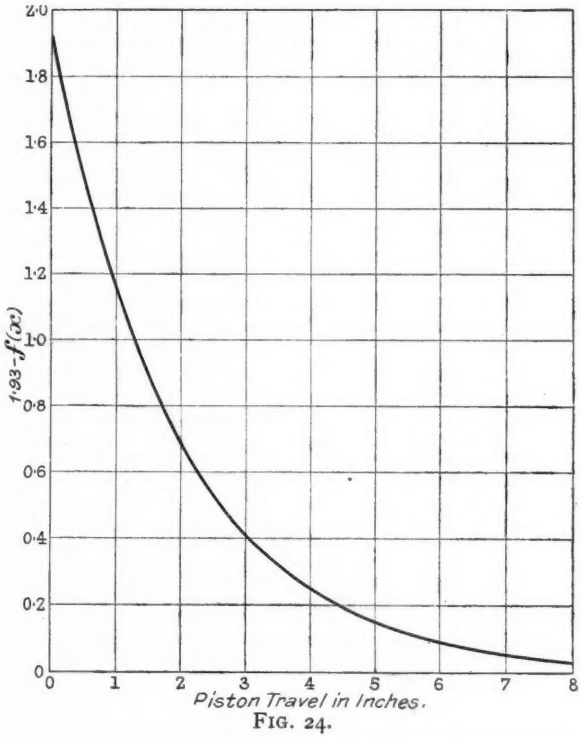

FIG. 24.

If the piston movement after the valve closes is x inches before the aeroplane is brought to rest, the total energy absorbed is

$$E_{y+x} + 3.98\,\pi y + 3.98\,\pi \times 1.93\,(1 - 10^{-0.225\,x}) \text{ inch lbs.}$$

and this $= \dfrac{3W}{g} \times V_0^2$.

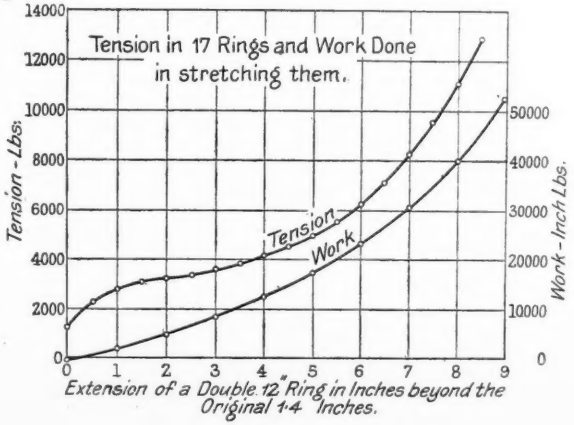

FIG. 25.

But

$$E_y + 3.98\pi y = 3W/g \ . \ (V_0^2 - \pi/91)$$

$$\therefore \ E_{y+x} - E_y + 3.98\pi f(x) = 7.68\pi$$

$$\text{or } E_{y+x} = E_y + 3.98\pi \{ 1.93 - f(x) \} \ . \ . \ . \ . \ . \ . \ . \ . \quad (6)$$

For a given value of π, determined beforehand, y can be found for a given vertical landing speed and hence E_y is known. If then the right hand side of equation (6) is plotted on the elastic work curve, the point of intersection will give the total extension.

In obtaining the above equation (4) has been used. This applies only when the retardation is due to the oleo alone and so the work done by the oleo is less than this quantity. The work done by the elastic should therefore be greater and so the value determined for $(y + x)$ is an inferior limit.

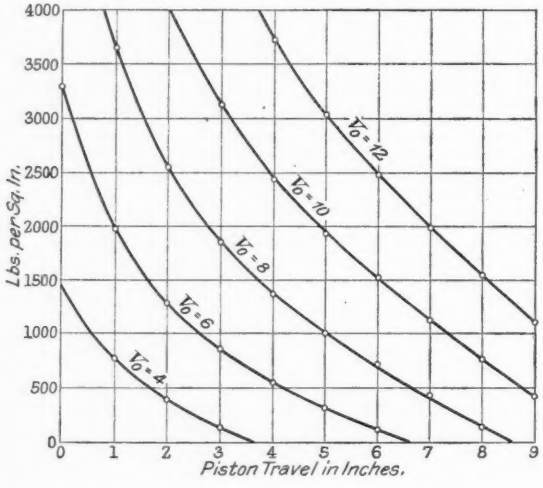

FIG. 26.

A superior limit is given by taking the retardation as constant after the valve closes; under these conditions the energy absorbed is

$$E_{y+x} + 3.98\pi y + 3.98\pi \ . \ \frac{x}{2}$$

and hence

$$E_{y+x} = E_y + 3.98\pi (1.93 - x/2) \ . \ . \ . \ . \quad (7)$$

For the particular case considered π was taken as 1,230 as the undercarriage was to be designed to be able to withstand the shock of a vertical speed of 12 ft./sec. and the maximum travel permissible is $9\frac{1}{4}$ inches. The following results are thus arrived at:—

V_0	y	E_y	$y+x$ Superior	$y+x$ Inferior
12	8.70	48100	9.22	9.19
10	6.70	27900	7.57	7.45
8	4.35	14100	5.59	5.42
6	2.08	5300	3.62	3.42
4	0.23	400	2.08	1.79

As will be seen the combination is effective up to a vertical velocity of 12 ft./sec. as far as piston travel is concerned. The maximum of thrust with this velocity is given after the piston has travelled 8.70 inches and is equal to 18,600 lbs. This corresponds to a load factor of about 5, which again is about right.

The oleo gear is not however known satisfactorily until the maximum pressure per square inch on the return stroke is determined.

To determine this step by step integration is necessary.

As before

$$p/\rho = V^2/2g \cdot (1 + Fl/m) \cdot A^2/a^2$$

where now A is only 2.21 sq. in. because of the piston rod

$$p = 28.1\ V^2$$

$$pA = 62.1\ V^2$$

If T_e is the tension in the elastic at any time we have originally

$$p = 0,\ T_e = 15{,}600 \text{ lbs.}$$

At any other time the upward force Z on the aeroplane is given by

$$Z = T_e - pA$$

But

$$2Z = \frac{W}{g} \cdot \frac{dV}{dt} = \frac{W}{g} V \frac{dV}{dx}$$

$$\therefore \int_{9-x}^{9} T_e dx = \int_0^x pA dx + \frac{W}{4g} \cdot V^2 \times 12 \text{ working in inch lbs.}$$

It is found that the maximum value for p is 1,350 lbs. and the final upward velocity of the aeroplane 6.9 ft./sec. The cylinder would therefore have to be stressed up to 1,350 lbs. pressure and not 1,230.

To see whether the velocity could be damped still more the orifices were reduced from $\frac{1}{8}$in. diameter to 3/32. The results are given below side by side with those for the $\frac{1}{8}$in. orifices.

Diameter of orifices, inches	$\frac{1}{8}$	3/32
Max. p on downstroke, lbs./sq. in.	1230	1750
Max. V on downstroke, ft./sec.	12	12
Piston travel, inches	9.20	8.36
Max. up thrust on aeroplanes, lbs.	18600	18200
Max. p on upstroke, lbs./sq. in.	1350	2450
Max. V on upstroke, ft./sec.	6.9	5.1
Final V upwards, ft./sec.	6.9	4.0

So far the wheels have been supposed very rigid so that they only absorb the kinetic energy of the wheels and axle. As pneumatic tyres have a good shock absorbing capacity their effect cannot be neglected and the modifications required to include them are outlined below (Fig. 27). The load deflection curve for the tyres is one supplied by the Palmer Tyre Company; it has been extended a little beyond the range given by them, but it is hoped that no error has thereby been introduced. The method now is entirely step by step integration and has been carried on until the velocity, vertically, of the aeroplane has been reduced from 12 to 2.3 ft. per sec. By this time 97 per cent. of the total energy has been absorbed. For the remaining 3 per cent. an approximate further movement cannot be far wrong.

Let W = weight of aeroplane less wheels and axle.
w = weight of wheels and axle.
$a - x$ = distance from cylinder head to piston head.
$r - z$ = distance from axle to ground.
then $x + z$ = aeroplane travel.
z = axle travel.
$V = \dot{x} + \dot{z}$ = aeroplane speed.
$u = \dot{z}$ = axle speed.
T_e = tension in elastic.
pA = pressure on piston.
P = pressure on ground.

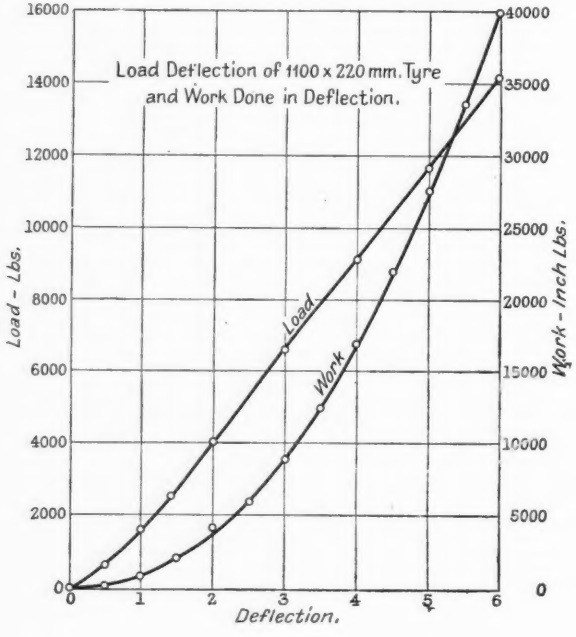

FIG. 27.

We have then

$$P - T_e - pA = \frac{w}{2g}\dot{u} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$T_e + pA = \frac{W}{2g}\dot{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

work done

$$= (T_e + pA)\,(dx + dz(+ (P - T_e - pA) + dz \quad . \quad . \quad (10)$$

and $p = 91\,(\dot{V} - u)^2$ as above.

Till P' the pressure at the hornblock = o, *i.e.*, until the initial tension in the elastic is overcome, $x = o$ and

$$P = -\frac{W+w}{2g}\dot{V} = \frac{W+w}{2g}V\frac{dV}{dz}$$

$$\int_0^{z_1} P dz = -\int_{V_0}^{V_1}\frac{W+w}{2g}\,.\,V dV = \frac{W+w}{4g}(V_0^2 - V_1^2).$$

But

$$P + P' - T_e = -\frac{w}{2g}\dot{u} = -\frac{w}{2g}\dot{V}$$

$$\therefore\ T_e - P' = -\frac{W}{2g}\dot{V}.$$

When

$$P' = o\ T_e = -\frac{W}{2g}\dot{V}$$

$$P = -\frac{W+w}{2g}\dot{V}$$

$$= \frac{W+w}{W}T_e$$

and therefore $\int_0^{z_1} P dz$ must be taken until $P = \frac{W+w}{W}T_e$.

From the load deflection curve of the tyre we find the deflection z_1 and from the work deflection curve the work done. Hence the velocity V_1, when the oleo begins to act, is determined.

When the oleo is acting step by step integration is done as follows:—

The equations (8) and (9) become respectively

$$(P - T_e - pA)\,dz = \frac{w}{4g}(u_1^2 - u_2^2)$$

$$(T_e + pA)\frac{V}{u}dz = \frac{W}{4g}(V_1^2 - V_2^2)$$

where suffix 1 refers to speeds at the beginning and 2 at the end of each interval taken and V/u is an average value for the interval. This form of the equations is used so long as u is greater than $\frac{1}{2}V$.

When u is less than $\frac{1}{2}V$ the equations are taken in the form

$$(P - T_e - pA)\frac{u}{V-u}dx = \frac{w}{4g}(u_1^2 - u_2^2)$$

$$(T_e + pA)\frac{V}{V-u}dx = \frac{W}{4g}(V_1^2 - V_2^2)$$

and average values taken for $u/(V-u)$ and $V/(V-u)$.

Applying this method to the same aeroplane as before, the analysis brings out the following points:—

(1) The axle is first brought to rest. The tyre deflection is increasing more and more slowly.

(2) The axle remains practically at rest, but the velocity of the aeroplane is falling steadily.

(3) The axle begins to move downwards again and the tyre deflection increases and then the axle comes to rest once more.

The load on the tyres is now a maximum and of the order of 12,000 lbs., this being also the upward thrust on the aeroplane.

The approximate further extension of the elastic is 0.3 inches.

The values of V, x and z at end of the various stages are as under:—

	Initial.	1st Stage.	2nd.	3rd.
V	12	9.8	6.8	2.3
x	0	2.2	5.6	7.6
z	0	4.3	4.3	5.1

From this investigation the initial 100600 inch lbs. of energy (half that of the aeroplane) are absorbed as under:—

Elastic	...	38600	inch lbs.
Wheel	...	28800	,, ,,
Oleo	...	33500	,, ,,

giving a total of 100900 inch lbs. An error of 300 in 100,000 is quite negligible.

As will be seen from the calculations for the greater part of the piston travel the valve is open, but instead of opening almost instantaneously the piston has travelled 0.7 inches before this occurs.

With 1,230 as the value of π in the former work the maximum elastic extension is 9.2 inches and the maximum load 18,600lbs. as against 7.9 inches and 12,000lbs. when the wheels are considered.

The presence of the pneumatic wheels therefore reduces the maximum load thrown on the struts by 35 per cent. and piston travel or elastic extension by 14 per cent.

The details of step by step integration are given in the Appendix as they form a guide as to the size of the intervals to be taken.

In both investigations the energy absorbed by the axle is neglected; taking this to be the same as in the static case when the load is gradually increased to the minimum loads of 18,000 and 12,000lbs. it is found that the work done in deflecting the axle is roughly 12,000 inch lbs. in the one case and 5,000 inch lbs. in the other. These represent 12 and 5 per cent. respectively of the total energy.

On an assumption that the axle will give a proof load of 80 tons per sq. inch, approximately 7,500 inch lbs. represents the maximum strain energy of the axle under consideration. Any further work on the axle will be expended in plastic deformation.

The annexed graph (Fig. 28) of the travel of the aeroplane C.G. and of the axle centre from the time of the first contact with the ground till the vertical velocity is 2.3ft./sec. plotted against time may be of interest. The time in coming to rest is about a seventh of a second.

Resistance.

An undercarriage is an essential part of an aeroplane, but from the point of view of resistance is an evil as it may and often does provide 15-20 per cent. of the total resistance apart from that of the wings. In order to make the aeroplane as efficient as possible this resistance must be reduced to a minimum.

In an undercarriage the resistance is due chiefly to

(*a*) Struts.
(*b*) Wheels.
(*c*) Interference between the parts.

(*a*) *Struts.*—In the design of struts the influence of "interference" or the best streamline form and fineness ratio is important. In the case of horizontal members (such as the axle) the fairing should have a high fineness ratio (>3·5) in order that the flow may be stable with change of attitude.

(*b*) *Wheels.*—Numerous experiments have been carried out on the resistance of wheels; the resistance is reduced to a minimum by fairing from tread to hub and by adding tail fairing. Owing to the difficulty of attachment, tail fairing, however, is scarcely, if ever, used. Tread fairing inside and outside reduced the resistance of a wheel to about one third. (See R. & M. 207.)

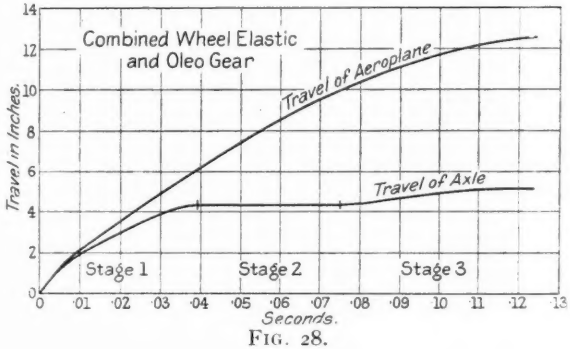

FIG. 28.

(*c*) *Interference.*—The chief interference is between the wheels and the struts with the shock absorber. Experiments carried out show that this interference is greatest with the wheels faired tread to hub on the inside, so that there appears little difference between rim and tread fairing when interference is taken into account. The best form of fairing for the wheels is tread fairing away from the struts and rim fairing towards it. (See C.I.M. 56.)

The two reports mentioned refer to wheels 800 × 150 mm. and 750 × 150 mm. respectively.

Experiments carried out in Boulton and Paul's 4ft. channel on a model of the Bourges undercarriage show that with tread fairing outside and rim fairing inside on wheels 900 x 200 mm. the interference was quite negligible. With larger wheels the elastic shock absorber and the struts are brought relatively nearer to the wheel and so this result is not at all surprising.

An interesting example showing how the resistance of the undercarriage can be reduced by fairing is the case of the B.E.2C. As originally constructed the resistance at 100ft./sec. was 19.4lbs. This was reduced to 14.3lbs. by :—

(*a*) Tread fairing on the outside of the wheels,
(*b*) Covering the axle fairing over,
(*c*) Fairing the elastic shock absorber,

that is, the resistance of the unit was reduced 26 per cent., and of the aeroplane about 5 per cent.

On the Bourges undercarriage the effect of fairing the elastic shock absorber was to reduce the resistance of the undercarriage by 8 per cent.

In order to obtain satisfactory results for the resistance, former experiments have shown clearly that it is essential to test not separate parts but the complete unit, for in this way only can the uncertain factor of the interference be eliminated.

To throw further light on the development of the oleo gear specimen modern undercarriages of this type will be described. The examples shown are :—

Small machines	...	Siddeley	Siskin.
Medium ,,	...	Boulton	Bourges.
Large ,,	...	Bristol	Braemar.

Siskin Gear.

In the Siskin undercarriage a triangulated structure is mounted on the fuselage from points near the root of the bottom wing spars, and from the apex of the structure radius rods are carried forward to the wheel axle. A pair of oleo legs are jointed to the axle on the inner side of the wheels and sustain the fuselage at the engine plate. The oleo leg is designed with large amplitude, the rubber acting conjointly with the oil dashpot throughout the stroke (Fig. 29).

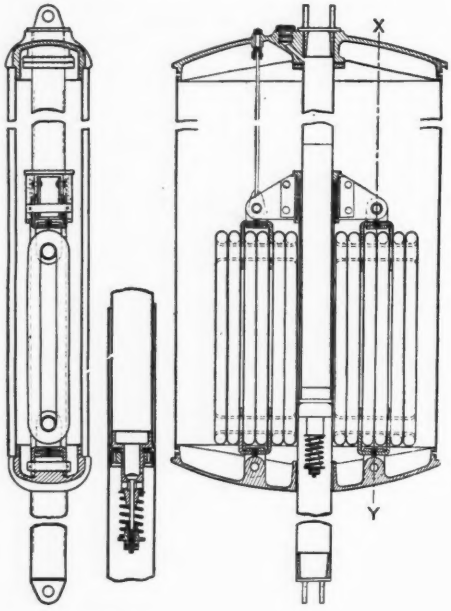

FIG. 29.

The leg gear consists of a pair of tubular telescopic members which together form the oleo dashpot, and which are maintained fully extended by a series of shock absorber rings mounted on suitable spools. The external telescopic member is jointed to the wheel axle, and carries the upper spool at its upper extremity. The internal telescopic member attaches to the fuselage and carries the piston head in which is mounted the pressure relief valve and constant leak holes. Aluminium end castings are arranged to support the fairing, which encloses the shock absorber rings and mounting spools. The lower spools are anchored to the lower end casting, which is free to slide on the central tubular member, and in con-

sequence the load imposed by the shock absorber rings is transmitted by the fairing to the upper end casting. An initial tension is given to the rings and the possible extension of the gear limited by a check cable anchoring the upper spools to the upper end casting.

Bourges Gear.

(Figs. 30 and 31.) In the Bourges undercarriage Vee struts are arranged near the ends of the bottom centre wing section directly under the engine mounting struts. The two axles are jointed to the fuselage on either side, and incline outwards to the Vee struts through which they are guided in a horn block. The wheel is mounted on an overhung portion, allowing for quick and easy removal. Suspension is by rubber rings and oleo dashpot, but in this instance the two systems are entirely separate. The oleo gear is built into the hornblock and lies

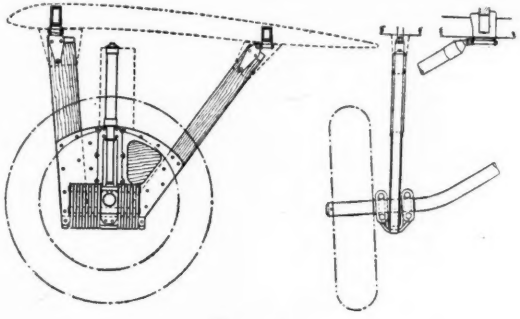

FIG. 30.

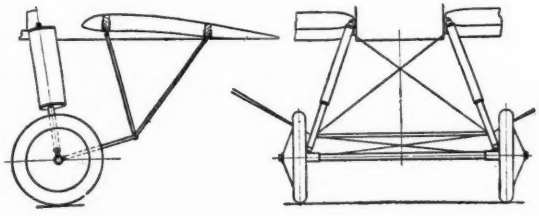

FIG. 31.

into the plane of the Vee struts thereby giving a minimum of resistance. The rubber rings are mounted on axle frames on either side of the Vee struts and pass under the apex of the Vee in the usual manner. Owing to the rearward inclination of the axle from its point of support on the fuselage, the ground reaction on the wheel gives rise to a couple tending to roll the axle over and cause the wheels to track incorrectly. This is provided against by arranging 10 rings forward of the axle and seven to the rear, the additional rings producing a correcting couple of the necessary magnitude for all relative positions of wheel and hornblock. Usual practice is inverted in the construction of the oleo leg (Fig. 32). The piston head and relief valve is carried by the internal telescopic member, which seats directly on the axle, and the external member is bolted up rigid to the hornblock. It is to be noticed that the total oil capacity is reduced as the piston head is advanced into the cylinder by reason of the volume of piston rod introduced. Allowance is made for the varying capacity by the provision of an air pocket above the oil, and the additional advantage is gained of a pneumatic cushioning action assisting the rubber suspension rings.

Braemar Gear.

(Figs. 33, 34 and 35.) In the Braemar Gear there are two wheels in tandem on either side of the fuselage. Each wheel is mounted on a separate axle, which is radiused from a point on the wing structure below the engine struts and is directed inwards towards the fuselage. An oleo leg connects the wheel end of all four axles to the fuselage. Motion of the wheels longitudinally is constrained by radius rods attached to the fuselage ahead of the undercarriage, the rear wheels being coupled to the front by a further pair of radius rods. The adoption of tandem wheels gives rise to a number of advantages. The weight of the machine is distributed on four wheels when taxi-ing without doubling the head resistance.

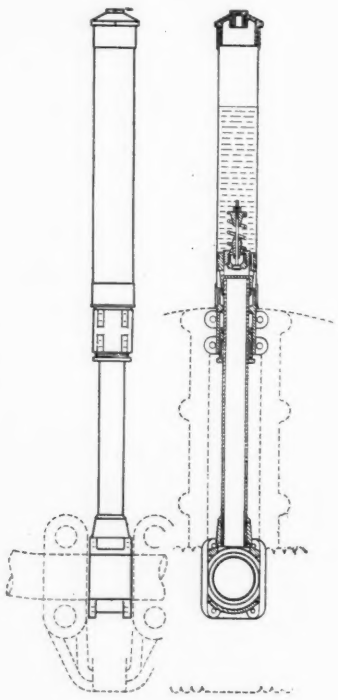

FIG. 32.

The forward pair of wheels may be set well forward of the centre of gravity of the machine, thus minimising the danger of nosing over in taxi-ing and landing, and this feature allows of a higher line of thrust than would otherwise be permissible. Also brakes may be fitted to the rear wheels since the breaking torque tending to nose the machine over is counteracted by the moment of the front wheel reaction about the C.G. The Braemar Gear is arranged so that the rear wheels are just under the centre of gravity of the whole machine, and the front wheels 4ft. ahead, and with this disposition the lengths of front and rear oleo legs and the strength of elastic, provide for a load distribution with the machine at rest of 37 per cent. on front wheels, 56 per cent. on rear wheels and 7 per cent. on tail skid. (Figs. 36 and 37). The oleo leg is constructed with the usual telescopic members, with the addition of two tubular guides arranged on either side, and is designed with the exceptionally long amplitude of 14in. During the first 7in. of stroke the oil

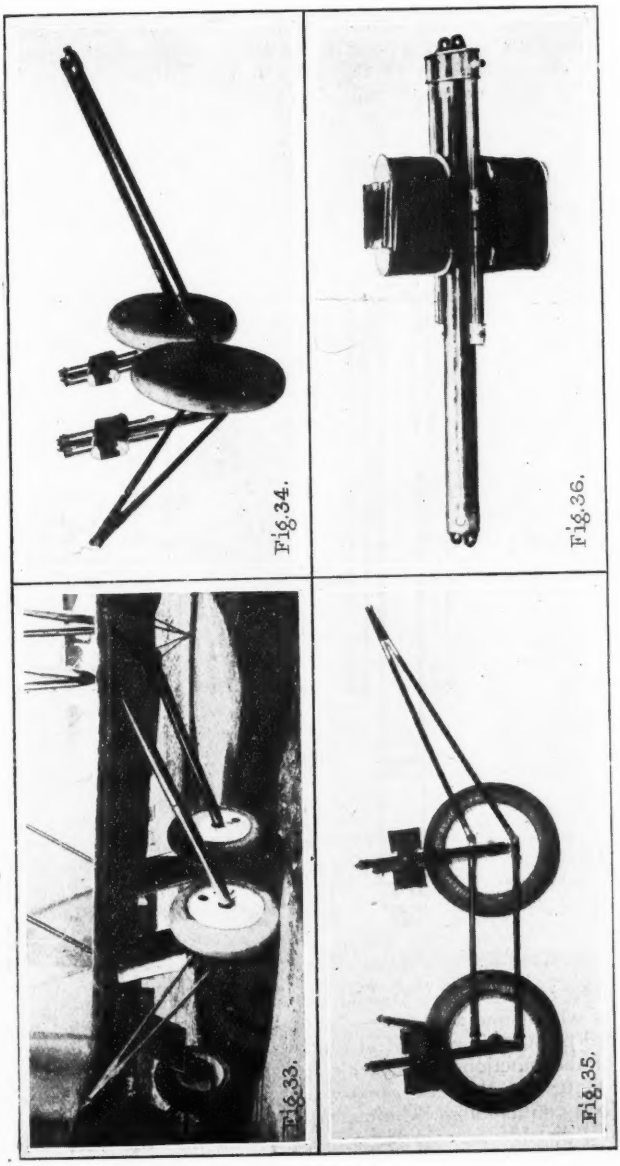

Fig. 33.

Fig. 34.

Fig. 35.

Fig. 36.

dashpot only is in operation and this is supplemented by the rubber suspension rings during the final 7in. This result is attained by the peculiar mounting of the suspension ring spool frames. The upper frame is rigidly fixed to the upper end of the external telescopic member whilst the lower frame is free to slide both on this member and on the tubular guides. The slide shows the gear in mid stroke. In the fully extended position the lower collars on the guide tubes are in contact with the under face of the spool frame. After the first 7in. has been traversed on oil alone the upper collars on the guide rod abut on to the lower spool frame and further motion then brings the suspension rings into operation, and the remaining 7in. stroke is made on oil and rubber suspension. The piston head is mounted on the internal telescopic member, and carries a relief valve which opens on the return stroke only. It will be observed that in taxi-ing, since the oil dashpot cannot sustain a static load, the rubber rings are always in operation,

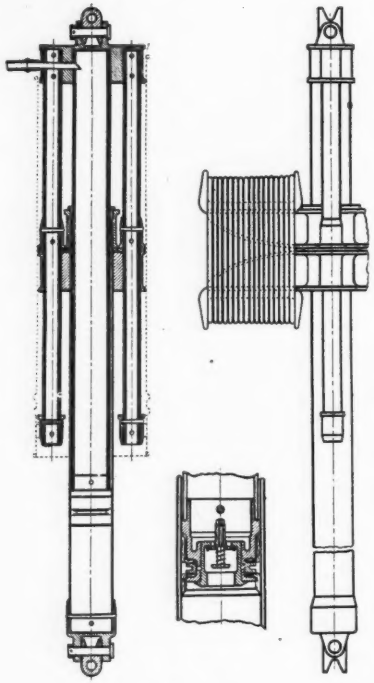

FIG. 37.

and the oleo leg is never fully extended until after the machine has taken off, when the weight of wheels and axle forces the oil past the reversed relief valve until the fully extended position is reached in readiness for the next landing. This partial separation of the functions of rubber rings and oleo dashpot would appear to be a desirable feature in that the greater portion of the energy represented by the vertical velocity in landing is immediately disposed of in the oil dashpot; an accompanying disadvantage would be expected in that the final extension is not positive, which may lead to the machine alighting on an uneven keel if one leg remains partly contracted after taking off.

It is understood that a relief valve opening on the landing stroke has been (or is to be) fitted, which would allow of the gear being accurately stressed in

uniformity with the fuselage. Further, since with a valve the maximum permissible load cannot be exceeded in the early part of the travel, the shock absorbing capacity is increased within the limits of the permissible load.

Tail Skid.

So far the support of the tail has not been discussed. It has already been shown that if the maximum permissible landing load on the tail is taken to be equal to the maximum down load designed for in flight, a structurally symmetrical and economical fuselage will result. The tail support usually takes the form of a skid attached to the body with a swivelling fork, and sprung with rubber shock absorber. Variations are shown in Fig. 38. In many cases it is desirable to control the swivelling motion from the pilot's seat to facilitate steering when taxi-ing. The design of the shock absorbing mechanism is simple. The energy to be absorbed when landing in condition (2) (wheel and skid simultaneously) is known from considerations already set out and it is merely essential that the area of the load-deflection diagram should be at least as great as this without exceeding the maximum permissible load. In certain cases difficulties arise where considerable deflection is required, as heavy side loads may be imposed on the skid structure when the skid projects far beyond the fork.

One of the important functions of the tail skid is to act as a brake, and in consequence the wear on the skid shoes is of great importance. The skid is usually heavily shod with high carbon or high manganese steel shoes of great hardness, but even these have rather a short life. In the case of twin-engined machines, which obviously do not require skid steering, the skid shoe is designed to have a low bearing pressure on the ground, and is preferably spoon-shaped. This has the effect of reducing side loads when the engines are used for turning. The use of heavy "sprags" on skids to give braking effect may set up big stresses in the fuselage, and consequently there is a limit to the braking effect to be obtained from the skid.

If the shock absorbing capacity of the whole undercarriage is to be improved considerably, more attention will have to be paid to the tail support. To a certain extent this has been done in the Braemar undercarriage, but it is by no means impossible that, in the case of large machines at least, wheel support—the practice of ten years ago—may be revived, and other means used for "braking" the aeroplane.

Brakes.

An important feature of a "safe" aeroplane is its ability to land in a confined space, and, since low landing speeds have a definite aerodynamic disadvantage, the designer endeavours to ensure that the run after landing shall be reduced to a minimum.

The methods proposed for this are as follows:—

(1) Designing the machine to have a large angle to the horizon when at rest.
(2) Providing adjustable flaps, expanding rudders, etc., to act as air brakes.
(3) Reversing the propeller.
(4) Providing sprags or hooks on the tail skid.
(5) Ditto on the main undercarriage.
(6) Ditto brakes on wheels.

Of these methods (1) is probably the most successful, and has certain indirect advantages. Unfortunately it results in heavy tail-skid loads in normal design.

(2) has been repeatedly tried and abandoned, as the effect is negligible compared with (1).

(3) has been proposed but not yet successfully carried out; in any case it is not effective with the engine stopped.

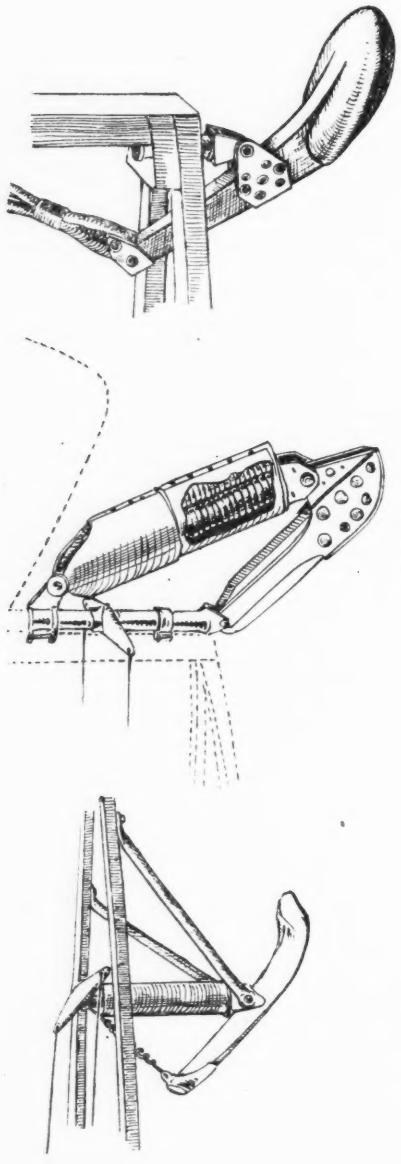

FIG. 38.

(4) if carried to excess damages the landing ground and is liable to put heavy stresses on the body which cannot be provided for accurately.

(5) is a common German practice, producing conditions not dissimilar to (4), but there is, as with (6), a tendency to turn the machine over on its nose, thus necessitating the use of leading wheels or skids. Experience has shown that the former are preferable.

The combination of (1) and (4) on small machines, and (1) and (6) on large machines seems to be the general trend of development.

In arranging for wheel brakes, special difficulties may be met with in the mechanical design owing to the heavy torque loads set up. The "Braemar" undercarriage has been designed to overcome the difficulties associated with wheel braking.

The calculation of the forces and moments arising from fitting wheel brakes is straightforward, and need not be gone into here. It is noteworthy, however, that the machine must be held in the stalled attitude in order that in the first part of the run advantage may be taken of the maximum air resistance at the comparatively high speed of travel. It will probably be found advisable, therefore, to apply the brakes when the speed is somewhat diminished. In considering the design of "leading" wheel gear it will be found on investigation that if this is to be of full value it must have adequate shock absorbing mechanism.

Oscillations after Landing.

Apart from the question of reducing loads in the aeroplane structure by the landing gear it is desirable that all oscillations should be damped as much as possible. The general method of determining the rate of damping follows directly from the examples given above for the oleo gear, but it will be necessary to take account of the work done on the axle. Owing to the great uncertainty as to the true values of hysteresis under actual conditions (referred to supra as "dynamic" hysteresis) no attempt has been made to follow up the example given with a quantitative determination of the damping of the oscillations. As a very rough approximation it is estimated that for the oleo gear with elastic and tyres, which has been discussed, the energy dissipated in the first oscillation would be somewhat as follows :—

Complete Undercarriage (*i.e.*, **Two Wheels).**

Total kinetic energy of aeroplane (vertical velocity 12ft./sec.) = 201,200 inch lbs.

Work on elastic	... ...	70,000 inch lbs.
,, oleo	... ...	64,000 ,, ,,
,, tyres	... ...	57,600 ,, ,,
,, axle	... ...	10,000 ,, ,,

Energy dissipated.	Down stroke.	Up stroke.
Axle	not known—neglected	
Elastic	negligible	
Oleo	64,000	28,000
Wheels	11,500	

Total energy dissipated = 103,500 inch lbs.
= 51 per cent.

This corresponds to a free drop of 2.24 feet and a rebound to 1.05 feet. The damping after the first oscillation is naturally less owing to the lower piston speed in the oleo gear.

It is distinctly shown that the rebound energy largely comes from the tyre. Captain Barnwell has suggested to me the use of solid tyres, and there certainly seems to be a possibility of development in this direction. It must be borne in

mind, however, that the tyre is called upon to absorb the kinetic energy of the wheel, and the tyre and axle that of the moving parts of the undercarriage, hence a definite shock absorbing capacity is required. At the same time the distribution of stress on the wheel is not so good as with a pneumatic tyre, and considerable increase in wheel weight may be expected with solid tyres.

Perhaps some form of cushion tyre may provide a satisfactory solution of the difficulty.

Taxi-ing: Periodic Oscillations.

Oscillations set up due to taxi-ing on uneven ground may of course be estimated on an assumed ground condition. These oscillations may be very serious, and if the period of the machine coincides with the " ridge and furrow " pitch an undercarriage might easily be broken. This is of course obviated by changing the taxi-ing speed. Shock absorbing in taxi-ing must be considered, and defects such as rolling, excessive bouncing, or hard running may occur with an undercarriage which is quite efficient for landing.

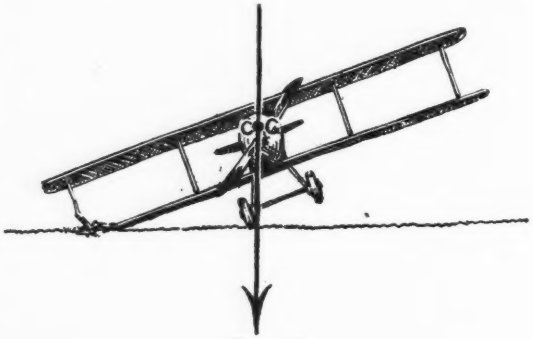

FIG. 39.

Landing on One Wheel.

Before attempting to draw deductions from the evidence submitted, there is one more case of landing to be dealt with, *i.e.*, landing on one wheel. In stressing an undercarriage for side load it is usual to assume either that the C.G. of the machine is over the wheel in contact with the ground or that one wing tip is just touching the ground. Fig. 39 shows these conditions occurring simultaneously. An arbitrary load factor of two on the normal loads, with the machine resting in the position discussed, has been customarily used. This is not really satisfactory, and some breakages of undercarriages have occurred under side load which are difficult to explain. There is no doubt that the majority of the shock absorption falls on the tyre under these conditions, and considerable experimental data will be required for an investigation into the actual loads induced in the structure. It certainly seems likely that if a general improvement is to be made in undercarriages a definite capacity for absorbing side shock will have to be provided.

Wheel Position.

To reduce " bucking " the wheels should be as nearly as possible under the C.G. of the aeroplane when the thrust line is horizontal, thus necessitating the use of leading wheels. The introduction of leading wheels permits the use of brakes, and when provided with proper shock absorbing mechanism will protect the machine against turning over as a result of striking obstacles on bad ground. The load on the tail is also relieved.

To reduce side loads and the danger of turning over sideways, the wheels should have a wide track. This helps to overcome the difficulty introduced by the change of wheel inclination due to big movement. It is clear that a really efficient undercarriage will be heavier and offer more resistance than the elementary types in use, but probably this increase would not be excessive.

* * * * * * * *

On examining the evidence set out above, one is particularly struck with the large amount of additional data necessary before satisfactory conclusions can be reached. I have drawn as far as possible on such sources of information as were available to me, and while another six months' work would undoubtedly have enabled me to present a more complete set of results, I felt that probably the discussion following this paper would achieve the same object in a more rapid manner, and that at the same time many people might be sufficiently interested to extend the work already done. I feel sure that there are many untapped sources of information, and I hope that the admittedly controversial nature of this paper may result in disclosing some of these.

SUMMARY AND CONCLUSIONS.

The following points seem to be indicated, though not of course in any way conclusively.

1. Wheels and Tyres.

Wheel " strain energy " is negligible.

Shock absorbing capacity increases with rate of loading.

Energy dissipated (" hysteresis ") increases with rate of loading.

The value of " Static "/" Dynamic " absorbing capacity ratio, as deduced from the Palmer Tyre Company tests, ranges from 72 per cent. for a one-foot drop to 95 per cent. for a six-foot drop. The value of the same ratio obtained from C.I.M. 744 is 70 per cent. There is considerable difference in method between the two sets of tests. From some special tests by the Palmer Company it is deduced that the percentage dissipated out of the total energy absorbed in static and dynamic tests is as follows :—

(*a*) Static hysteresis ... ... 8 per cent.
(*b*) Dynamic hysteresis ... ... 20 per cent.

The dynamic cases correspond to actual conditions.

Solid Tyres.

Solid or rather cushion tyres might possibly be used with advantage to reduce oscillations. They must have a shock absorbing capacity capable of dealing with the kinetic energy of the moving parts of the undercarriage. Considerable increase of wheel weight is to be feared with this system.

2. Rubber Shock Absorbers.

Even tensioning and consistent quality of material are important, and individual rings seem to give the best promise of fulfilling these requirements.

Shock absorbing capacity remains constant with varying rate of loading. Energy dissipated diminishes with rate of loading. (Boulton and Paul experiments.)

Mr. Turner states that with rates of loading corresponding to actual conditions the hysteresis of rubber shock absorber appears from preliminary experiments to be negligible. The details of these experiments are however not available.

Shock absorbing capacity decreases after repeated extensions.

Vertical Velocity.—Value of u is indeterminate, but should not be less than $V \sin \gamma$.

Load Factor.—Landing Factor should be of the same order as flight factor.

Oleo Gear Design.—Since to get high shock absorbing capacity a big movement of the leg is required, only a small part of the piston movement should be coincident with movement of the rubber. With this condition the damping is increased. To take full advantage of the oleo gear a relief valve is necessary, in addition to the constant leak holes, opening just before the maximum load on the structure is reached. The effect of using air cushions requires further investigation.

In order to get large travel certain obvious difficulties due to angular motion of struts, etc., have to be overcome. A large wheel base will assist this, and at the same time improve conditions for landing canted or side to wind. A large wheel base is also necessary with big travel to avoid "rolling" or swaying in taxi-ing.

Leading wheels have definite advantages, but must have a proper shock absorbing capacity.

The possible undercarriage arrangements are innumerable, but the advantages of various systems may be examined quantitatively by the methods outlined. It is reasonable to expect that a considerable improvement can be made on present practice by a slight sacrifice of flight performance.

In conclusion I have to thank those who have so kindly furnished me with information and assistance in the preparation of this paper. Particularly Mr. Thomas Sloper and the Palmer Tyre Co., Ltd., for valued information and special experiments on tyres, Capt. F. S. Barnwell, B.Sc., F.R.Ae.S., and the Bristol Aeroplane Co. for details of the Braemar Gear, Captain F. M. Green, A.M.I.C.E., F.R.Ae.S., and the Siddeley Deasy Co., Ltd., for details of the Siskin Gear, Mr. Turner of Luke Turner and Co. for information dealing with rubber shock absorbers, the Director of Research, for permission to quote several confidential information memoranda, and my assistant engineers, Mr. O. Glauert, B.A., for the work on the complete Oleo Gear Analysis, and Mr. H. J. Pollard Wh.Ex., A.F.R.Ae.S., for the preparation of the stress diagrams.

[A number of diagrams and photographs have unavoidably been omitted from Mr. North's paper.—EDITOR.]

APPENDIX.

An aeroplane of weight 7,500 lbs. strikes the ground with a vertical velocity of 12 feet a second. To find how the energy is absorbed by the wheels, elastic and oleo gear.

With the notation in the text.

Original $T_e = 1400$ lbs.
$W = 7300$ lbs.
$w = 200$ lbs.

$$\text{When } P' = 0 \quad P = \frac{7500}{7300} \times 1400 = 1440.$$

Hence tyre deflection = 0.9 inch
work done = 600 inch lbs. } from graph.

Half energy of aeroplane = 100,600 inch lbs.
$= 699\ V^2$.

$$V_1^2 - V_2^2 = \frac{600}{699} = 0.86$$

$$\therefore \quad V_2^2 = 143.14$$
$$V_2 = 11.96$$

Table 1. $u > \frac{1}{2}V$.

dz is chosen arbitrarily. P is the average value in the interval dz.

From a first calculation the average value x in the interval dz is determined and the value of T_e for this mean x is taken.

The initial value of u_2^2 and V_2^2 is 143.14.

To determine ϕ an average value of V/u is taken.

Table 2. $u < \frac{1}{2}V$.

dz is chosen arbitrarily and a value for a mean $u/V - u$ over the period was guessed. Mean values of P and T_e were taken throughout. The method was very tedious, especially in the later stages, when as many as five approximations were made on occasions to establish a satisfactory mean.

DISCUSSION.

Major-General R. BROOKE-POPHAM expressed his thanks for Mr. North's paper, which he said was an extremely valuable one. Only those who had been unfortunate enough to have to prepare lectures could realise the immense amount of work the preparation of this paper entailed. The design of civilian machines had still a tendency to be, perhaps unconsciously, too much influenced by military considerations, and he would like to emphasise the importance of not being hide-bound by the military necessities that arose during the war. Undercarriages were a particular instance of that general question. He thought the Vee-type undercarriage was evolved purely either for winning races or for military purposes. A large number of aeroplanes were sent out to France fitted with undercarriages which, from basic principles, were considered more suitable than the Vee-type, such as the F.E.2B., the Armstrong-Whitworth, and one or two others. These were afterwards changed to the Vee-type, but simply owing to the exigencies of war. There was, however, a limitation to what one ought to do in the way of putting on enormous carriages. The extreme limit was perhaps represented by the Voisin. Purely as an undercarriage, he thought that was perfect. One could not smash it on landing, and it was fitted with brakes and every convenience. The lecturer had not mentioned the cushioning effect of having the lower planes close to the ground. He had noticed it in the old B.E.3, a machine which he always looked upon with the greatest affection. It was easy to land, and landed very slowly, which he thought was due, to some extent, to the cushioning effect of the lower plane. He hoped the Chairman was not going to refute that by quoting light loading. The shock absorber seemed to be used in a better fashion on some machines than on others, chiefly due, he thought, to the method used in winding. Experiments had been carried out in regard to that lately at Farnborough. Perhaps someone from Farnborough would give his views. The object, he took it, was to let the shock absorber stretch easily at first, but absorbing more and more energy as it was extended.

The CHAIRMAN said they had there two at least of the persons originally engaged on the Oleo gear. Perhaps Mr. F. M. Green would speak.

Mr. F. M. GREEN said that the credit for first making an Oleo gear was due to Breguet, but its later development had been carried out in this country. The lecturer had not made it entirely clear that a landing gear had two very distinct functions, which did not always work together. One was to absorb the vertical shock of landing and the other to act as an elastic suspension when the machine was running over the ground.

STAGE 1. $u > \frac{1}{2}V$.

z in.	dz in.	$av \cdot x$ in.	P lbs.	T_e lbs.	$\frac{\rho A}{362}(v-u)^2$	$\int (P - T_e - \rho A)\, dz$	$\frac{V^2}{\phi} \div 18.05$ $u_1^2 - u_2^2$	u_2^2	$\frac{V}{u}$	$\int \frac{V}{\phi}(T_e + \rho A)\, dz$	$V_1^2 - V_2^2$ $\phi \div 680$	V_2^2	V_2	$V_2 - u_2$	$\frac{V_2 - u_2}{u_2}$	dx
0.9	0.5	.01	1080	1430	40	255	13.66	143.14				143.14				
1.4	0.2	.03	2800	1460	250	218	11.69	129.48	1.047	750	1.11	142.03	11.92	0.54	.047	.024
1.6	0.2	.06	3300	1520	700	216	11.58	117.79	1.096	370	0.54	141.49	11.89	1.04	.096	.019
1.8	0.2	.08	3800	1560	1170	214	11.48	106.21	1.150	500	0.74	140.75	11.86	1.55	.150	.030
2.0	0.2	.14	4320	1670	1830	164	8.80	94.73	1.215	650	0.95	139.80	11.82	2.09	.215	.043
2.2	0.2	.20	4830	1800	2470	112	6.00	85.93	1.270	870	1.29	138.51	11.77	2.50	.270	.054
2.4	0.2	.27	5340	1940	2980	84	4.50	79.93	1.309	1111	1.63	136.88	11.70	2.76	.300	.061
2.6	0.2	.34	5850	2080	3430	68	3.64	75.43	1.340	1305	1.92	134.96	11.62	2.94	.340	.068
2.8	0.2	.41	6370	2200	3570	116	6.22	71.79	1.360	1500	2.20	132.76	11.52	3.05	.360	.072
3.0	0.2	.50	6860	2340	4280	48	2.57	65.57	1.410	1620	2.37	130.39	11.42	3.32	.410	.082
3.2	0.2	.59	7380	2420	4430	106	5.68	63.00	1.424	1890	2.78	127.60	11.30	3.36	.424	.085
3.4	0.2	.68	7890	2570	4900	72	3.85	57.32	1.474	2020	2.96	124.64	11.16	3.59	.474	.095
3.6	0.2	.79	8400	2680	4900	164	8.84	53.47	1.506	2290	3.36	121.28	11.01	3.70	.506	.101
3.8	0.2	.95	8900	2810	4900	238	12.75	44.63	1.625	2490	3.62	117.64	10.85	4.17	.625	.125
								31.88	1.888	2730	4.01	113.63	10.66	5.01	.888	.178

STAGE 2. $u < \frac{1}{2}V$.

x in.	dz	$\frac{V-u}{u}$	P lbs.	T_e lbs.	pA const. at first	$\frac{V-u}{u}\ \psi\ (P-T_e-pA)\,dx$	$u_1^2 - u_{g^2}$ $\psi \div 18.65$	u_{g^2}	u_2	$\frac{V}{V-u}$	$\frac{V}{V-u}(T_e+pA)\,dx$ ϕ	$V_1^2 - V_{g^2}$ $\phi \div 680$	V_{g^2}	V_g	$V_g - u_g$	$dz \quad z \quad dp\frac{n-V}{n}\,dx$	z
1.04	0.2	.688	9300	2980	4900	256	13.70	31.88	4.24	1.688	2070	4.37	113.63	10.45	6.21	.180	4.18
1.24	0.2	.432	9640	3060	4900	160	8.58	18.18	3.10	1.432	2350	3.40	109.25	10.28	7.18	.086	4.27
1.44	0.2	.248	9850	3140	4900	103	5.52	9.60	2.02	1.248	2086	3.06	105.79	10.13	8.11	.050	4.32
1.64	0.2	.147	9940	3200	4900	45	2.44	4.08	1.28	1.147	1820	2.68	102.73	10.00	8.72	.029	4.35
1.84	0.2	.032	10040	3240	4900	28	1.53	1.64	0.33	1.032	1750	2.57	100.05	9.87	9.54	.006	4.35
2.04	0.2		10050	3300	4900	6	0.32	0.11		1.000	1670	2.45	97.48	9.75	9.75		4.35
2.24	0.36		10050	3400	4900					1.000	2990	4.40	95.03	9.52	9.52		4.35
2.60	1.0		10050	3660	4900					1.000	8500	12.59	90.63	8.83	8.83		4.35
3.60	1.0		10050	4200	4900					1.000	9100	13.38	78.04	8.04	8.04		4.35
4.60	1.0		10050	5060	4900					1.000	9960	14.66	64.66	8.04	7.07		4.35
5.60	0.2	.065	10060	5780	4900	— 8.1	— 0.43	0.43	0.66	1.066	2240	3.29	50.00	7.07	6.83		4.36
5.80	0.2	.150	10060	6050	4900	— 17.8	— 0.95	1.38	1.17	1.150	2520	3.70	46.71	6.83	6.17	.010	4.36
6.00	0.2	.580	10100	6380	4900	— 73.2	— 3.93	5.31	2.30	1.580	2940	4.31	43.01	6.56	5.39	.040	4.40
6.20	0.1	.760	10200	6700	4400	— 61	— 3.26	8.57	2.93	1.760	1950	2.77	38.70	6.22	3.92	.060	4.46
6.30	0.1	.910	10500	6900	3410	+ 17	+ 0.93	7.04	2.76	1.910	1070	2.90	35.93	5.99	3.50	.080	4.54
6.40	0.1	.840	10700	7000	3390	26	1.40	6.24	2.50	1.840	1910	2.81	33.03	5.75	2.99	.090	4.63
6.50	0.1	.755	10900	7200	3390	31	1.66	4.58	2.14	1.755	1800	2.73	30.22	5.50	3.06	.084	4.71
6.60	0.1	.655	11200	7400	3460	22	1.19	3.39	1.84	1.655	1800	2.64	27.49	5.24	3.06	.084	4.80
6.70	0.1	.562	11320	7600	3500	12	0.66	2.73	1.65	1.562	1735	2.55	24.85	4.99	3.15	.066	4.86
6.80	0.1	.490	11480	7820	3390	13	0.71	2.02	1.42	1.490	1670	2.46	22.30	4.72	3.07	.056	4.92
6.90	0.1	.422	11600	8040	3320	10	0.54	1.48	1.22	1.422	1610	2.37	19.84	4.45	3.03	.049	4.97
7.00	0.1	.374	11700	8300	3130	10	0.54	0.94	0.97	1.374	1570	2.31	17.47	4.18	2.96	.042	5.01
7.10	0.1	.309	11780	8540	2980	8	0.42	0.52	0.72	1.309	1505	2.21	15.16	3.89	2.92	.037	5.05
7.20	0.1	.229	11840	8800	2860	4	0.32	0.30	0.55	1.229	1435	2.11	12.95	3.60	2.88	.031	5.08
7.30	0.1	.163	11886	9080	2640	2.6	0.14	0.16	0.40	1.163	1365	2.00	10.84	3.29	2.74	.023	5.10
7.40	0.1	.115	11900	9360	2320	2.5	0.13	0.03	0.17	1.115	1300	1.91	8.84	2.97	2.57	.016	5.12
7.50	0.1	—	—	9640	2190	—	—	—	—	1.000	1180	1.74	6.93	2.63	2.46	.012	5.13
													5.19	2.28	2.28	—	—

In early landing gears designed by the speaker, the travel of the gear was long, and the energy absorbed in the oil was greater than is now found necessary. What the lecturer described as new in the Braemar gear actually took place in the F.E.2 landing gear, as the spring did not come into action till the gear was partly closed.

The value of the use of oil was that it was lighter than steel or rubber for absorbing energy, and also that it dissipated the energy and prevented the aeroplane from bouncing.

If the oil were allowed to exercise its full damping effect when the aeroplane was running over the ground, then the axle would not move fast enough, and the springing would be hard In the earlier landing gears this was looked after by means of an air chamber; more recently it was found possible to obtain the same effect by simpler means. The leak holes were made to act as the return passage for the oil, and no non-return valve was provided; by this means the oil is prevented from returning to the under side of the piston fast enough to exert much damping on the next bump.

The lecturer had shown a new type of gear on the Bourges aeroplane, in which the usual arrangement had been inverted. It seemed possible that there might be trouble in preventing loss of oil from leak. The advantage of the type used by the speaker was that the oil never leaked out of the gear, as any oil that got past the piston returned by gravity to the lower part of the Oleo leg. In actual practice, aeroplanes had flown for more than a year without perceptible loss of oil.

The value of the Oleo landing gear for war aeroplanes had been a subject of controversy; no one disputed that it was a good landing gear, but in the early examples it was heavier and had more resistance than the Vee gear. In active service the pilots preferred to have the highest possible performance, even if the aeroplanes were smashed more frequently in landing. They were probably right.

The Oleo gear has developed since then, and the actual weight of the Siskin landing gear, shown by the lecturer, was practically identical with that of the S.E.5 landing gear, although the S.E.5 was a slightly lighter aeroplane. The resistance was probably about the same; it was certainly not high, as the aeroplane had made a particularly satisfactory performance in regard to speed.

It seemed that we have arrived at a stage when we could make an Oleo gear that would absorb twice the energy of the Vee gear for the same weight and resistance, and the speaker considered that there was now no excuse at all for not using this type of gear.

It was a pleasure for the speaker to be able to express his gratitude to Mr. Sloper, of the Palmer Tyre Co., for the assistance he had always rendered in the development of line wheels. At a time when the demand was small Mr. Sloper and his company were farsighted and patriotic enough to do an immense amount of work, with the result that there had been less trouble with wheels and tyres than with almost any other aeroplane material during the war. Our thanks were also due to Mr. North for the large amount of information the lecture contained.

Squadron Leader F. H. BRAMWELL also expressed appreciation of the paper and said up to the present it had been difficult to get knowledge of load factors for undercarriages. One had concentrated upon the rest of the machine during the war and left the undercarriage to look after itself. Mr. North suggested 15ft. per second for the vertical velocity on a gliding descent. Undercarriages on existing machines might be divided into three classes:—(1) Weak, (2) reasonably strong, and (3) very strong. R.A.E. test figures put the value of the vertical velocity to reach the breaking load of a weak undercarriage at 6ft. to 9ft. per sec., of a strong undercarriage, 9ft. to 12ft., and of a very strong undercarriage, 12ft. to 18ft. The load factors in the three cases were about 4, 5 and 9. These

test figures agreed very well with the 15ft. per sec. suggested by Mr. North as a suitable figure. The division into the three classes was obtained from the results of practice. A reasonably strong carriage was one that did not break up frequently, while a weak undercarriage was liable to break. The question of design of undercarriages was still in the experimental stage, and they had to thank Mr. North for putting his methods of calculation before them. A plain calculation of the load factors of undercarriages did not give what was wanted. He could instance two different machines with undercarriages of different types; one of these had a minimum load factor calculated on static load of about 6 or 7 and breakages were fairly common, though it was fitted with a rubber shock absorber; while the other had a load factor in the main struts of the undercarriages of only 1.8, but had not broken up, except on one occasion. The one occasion could be better described as a crash than a bad landing; needless to say in the second case an Oleo shock absorber was fitted.

Mr. North gave the value for the density of the oil as practically the same as for water; it was, apparently, a very heavy oil. And he gave a definite value for the coefficient of frictional resistance. What sort of oil did he suggest using? The frictional coefficient for oil would change rapidly with change of temperature, and one would imagine that on a hot day the amount of energy absorbed by an Oleo gear would be much less than in winter, when oil sometimes froze solid. For that reason it seemed possible that these calculations had gone to a little further refinement than was quite necessary, and it was doubtful whether one need go to such an extent in the step-by-step integration.

He was glad Mr. North mentioned the question of wind resistance on different parts and the interference effects between them, because the data available on such interference effects were very limited. Mr. North had mentioned in this instance only the effect between the wheels and the struts of the undercarriage, but he could no doubt give them figures for other effects, such as those of engine nacelles between the wings. It was important that aeroplane designers should have their own wind channels for measuring interference effects on the machines on which they were engaged. To get the best results models should be made of each machine and put in the channel and the models then carved down to get the minimum resistance on the various parts with the interference effects present. It will be of great value if each designer has his own wind channel for routine test work; the channels at the National Physical Laboratory and similar institutions should be kept entirely for pure research work.

Mr. H. GRINSTED said Squadron Leader Bramwell had already given the results obtained by comparison of the loading tests of undercarriages carried out at Farnborough. The comparative results thus deduced were compared with the experience of pilots who had landed many times on the types of undercarriages tested, and the opinions expressed independently by the pilots were surprisingly in agreement with the results deduced from loading tests.

Undercarriages that had failed at low loads on static tests did not necessarily fail frequently in actual use. Those undercarriages were often more satisfactory because they generally allowed a large travel for the axle and on account of the smaller forces involved they gave a more comfortable landing.

With regard to the method of winding the elastic shock absorber it is found that the method of winding in which the elastic is almost horizontal at the start so that the load applied to the axle is small to begin with and gradually increases is more satisfactory as to comfort of landing than the method in which the elastic is vertical.

The divided axle type of Vee undercarriage appeared generally to be the most satisfactory as regards comfort of landing and also freedom from breakage, but this is, he thought, due to the fact that the types using the divided axle have also the "flat wound" elastic.

Captain WILKINSON asked whether the tests on the tyres had been taken with the tyres revolving. He thought the effects shown on the screen could not occur if the wheels were in motion.

Mr. T. W. K. CLARKE said the paper had been of particular interest to him, especially the analysis of the motion when landing. Some months ago he set himself a similar sort of analysis when engaged on the design of an undercarriage, and some of Mr. North's information had corrected some of his conclusions.

The first point on which he would like information was, how was the experiment to determine the reaction of the tyre during the compression and subsequent expansion carried out? He presumed from the later remarks that the figures were those taken from the Palmer Company's figures.

Mr. North had raised the point as to what should be taken as the limiting vertical velocity to be allowed for when landing and suggested the minimum value of $V \sin \gamma$, γ being the gliding angle for speed V. He (Mr. Clarke) also thought that was the best value to take as it allowed landing to be carried out in an aerodrome when the ground was invisible owing to fog or darkness. Mr. North remarked that in such cases the machine would "just collapse" on reaching the ground. He thought they would prefer to say "just not collapse." In his own analysis he had used 18ft. per sec., but this agreed quite well with Mr. North's 15ft., as it was applied to a somewhat higher wing loading. The lecturer suggested that for bigger machines one could design for bigger values of "u," the vertical rate of fall, but he was inclined to disagree. For the energy any type of undercarriage could absorb was—as in the case of anything in the nature of a spring—proportional to the weight of that undercarriage, that is proportional to the weight of the whole machine as the undercarriage was a certain proportion of it. Hence it followed $W \times u^2$ must be proportional to W, or the vertical velocity u must remain roughly the same in all cases. The big machine had the advantage, however, that the ground was relatively flatter.

He would like to know whether any lateral force was allowed for when stressing on the wheel when landing? In such cases he had taken that to be one-fifth of the normal force, and he would like Mr. North's opinion on that. He had taken this because it was the biggest possible figure as the tyre would almost certainly begin to slip sideways over the ground when the lateral force was beyond that limit. Messrs. Palmer's figures on the hysteresis effect of the tyres were to him quite new and very interesting. Was he right in understanding that the hysteresis time effects in the cases of tyres and rubber shock absorbers were opposite to one another. (The LECTURER: Apparently.) These hysteresis effects when applied to his own analysis would probably account for a rebound which at present appeared by his diagrams more than one would expect. At first sight such differences as 15 per cent. in the value of the dissipated energy between the two cases of dynamic and static compression might be thought to be due to the difference between adiabatic and isothermal compression of the air, but so far as he could see, this could not account at the most for more than about 3 per cent.

At one time he had to use rubber to a great extent for motive power, and he then had formed the following few rough and ready rules:—(1) Rubber after its first good stretch lost at least 10 per cent. of its resilience. (2) Black para rubber had about 10 per cent. more resilience than red antimony rubber, but it perished quicker. (3) Where there was relative motion among the strands lubrication was of immense value. (4) The greatest resilience was in the surface of the rubber, so that for resilience flat thin sections were better than large or square sections. (5) That rubber has about five times the resilience of steel. In the analysis of the oil flow in the Oleo gear Mr. North used the term Fl/m in connection with the orifice. It was a coefficient to which he had always understood it was difficult to give a definite value. It was hard, therefore, to say without

experiment what would be the rate of discharge of the oil through the ports; moreover, the proximity of the release valve to the ports might cause the fluid pressures upon it not to be the same as those over the piston, which would introduce another error in the giving of any definite value to the pressure at which the release valve would operate. Had Mr. North made any experiments in these directions? With regard to such experiments it was interesting to note that although it might be somewhat difficult to carry out such experiments under actual conditions owing to the very high pressures and small sizes to be dealt with, yet it was quite easy to keep the scale effect coefficient Vl/v (which was all that mattered) the same by using larger models and smaller pressures. He might mention in this connection that the engineer of the Hydraulic Power Company had kindly told him that he had facilities at their yard which he would gladly make available for such experiments. The consideration of the coefficient Vl/v also showed that practically all the orifice resistance is due to turbulence rather than viscosity.

Finally, he would like to congratulate Messrs. Boulton and Paul on the considerable scientific use they have made of their wind channel.

Mr. A. H. TILTMAN said he would like to hear Mr. North's opinion on the possibilities of pneumatic shock absorbers. If springs, elastic and oil could be dispensed with, there would be a great saving in weight. The constructional difficulties would be severe—designing an airtight piston—but he had reason to believe it would be possible to overcome them. It would of course be necessary to damp the recoil, but it should also be possible to do this pneumatically.

Mr. A. J. SUTTON PIPPARD said Mr. North's paper was the more valuable as very little had previously been published on the subject of undercarriages so far as he was aware. Mr. North's treatment of the Oleo gear would be extremely valuable in future design work. During the war undercarriages were always designed and compared on the static load factor, which was not quite satisfactory. A proper dynamic basis was essential. What did Mr. North mean when he said the minimum value of $V \sin \gamma$ should be taken for u and that the undercarriage should just smash if it hit with that velocity? One could not always guarantee one's materials and a factor on this velocity would be advisable. It would be greatly to the advantage of the Society if they could get a corresponding paper dealing with seaplane undercarriages and the design of hulls for flying boats.

The CHAIRMAN said he could not too strongly support Mr. Pippard's plea for members who had specialised to come forward. It was difficult to write papers, but he would like members who had special knowledge of a subject and who did not wish to write papers to make their friends do it. That was a vicarious way of helping the Society.

Mr. O. GLAUERT said he was the unfortunate author of the Oleo analysis, and he would like to answer Mr. Bramwell and Mr. Clarke with regard to the value of F (the frictional coefficient). The Oleo gear idea had been in use some considerable time, for hydraulic buffers and experiments showed that variations in temperature showed very little variation for the value of F. The largest variation was due to the metal surface and not to the liquid. The chief factor must be that the oil was pressed through the orifices at a very high velocity. The elastic shock absorber apparently dissipated no energy, while the wheel dissipated far more energy than the static tests had led one to believe. In every direction they should strive to have full-scale tests resembling those occurring in practice.

Mr. J. L. LAKE said other members like himself might remember a lecture given about three years ago by Captain Walpole, who asked manufacturers for assistance on certain aeroplane accessories which were not so perfect as he would wish. The Palmer Tyre Company were mentioned in that lecture and thanked for the work they had done, and judging from what Captain Green has just said, Mr. Sloper and Mr. Grey, of the Palmer Tyre Company, have added since that

time to their good work on behalf of undercarriages. Captain Walpole's invitation to manufacturers for help was the means of bringing forward Mr. Archibald Turner (of Luke Turner and Co., of Leicester), who had been working somewhat in the background on the subject of rubber shock absorber cord. It gives one pleasure to know, as Mr. North has shown us, that his good work has been so well appreciated.

The CHAIRMAN proposed a hearty vote of thanks to Mr. North for his lecture, and incidentally said he thought it was a suitable occasion for them to congratulate themselves upon having achieved another great aerial victory in the success of the Australian flight on a British machine made by the distinguished armament firm of Vickers, who also made the machine which achieved that first direct flight from the other side of the Atlantic. This last victory was flown by men whom we were proud of claiming as Britishers. He had pleasure in asking the meeting to applaud our Australian friend, Mr. Ross-Smith.

A vote of thanks was also accorded the Chairman, on the motion of General BAGNALL WILD (Chairman of the Society).

Captain F. S. BARNWELL (*communicated*): As regards axles:—The axles first used on the "Bristol Braemar" were of solid high-tensile steel and were of a tapering cross section of "I" form. These proved quite satisfactory, and very economical in weight, to resist the stresses due to vertical loads. But their fore and aft stiffness was so low that king posts and tie-rods had to be added to enable them to stand up satisfactorily under the drag loads. The job became therefore rather elaborate and expensive, so axles of tubular form were substituted.

I mention this as perhaps of some interest, but I appreciate that Mr. North had in mind built-up steel axles of a more or less rectangular box section. An axle of this type, having correct cross sectional proportions throughout its length, should give the lightest possible form; how much weight would be saved compared to tubular axles of equal strength, and at what increase in cost, seems a matter for profitable investigation.

As regards shock absorber elastic:—I should like Mr. North to affirm that when he mentions "rubber rings," he means a ring of the standard braid-covered cord, not a ring of bare rubber.

As regards Oleo gear:—I am not certain that I see the value of a relief valve, and we do not propose to fit such to the Braemar gear; a non-return valve, of generous proportions, does appear to be of value in taxi-ing. If a relief valve be fitted in the form of gear fitted on Braemar, then, should the vertical velocity be excessive, excessive energy will fall to be absorbed by the elastic; whilst if no valve be fitted, then will the excessive energy fall to be absorbed by the dash-pot. In the former case one would expect complete telescoping and excess energy remaining to cause shock on abutment, in the latter case excess pressure in the dash-pot but no abutment shock. I realise that correct proportions for the vent hole are very important, but I am not clear as to the advantages of a relief valve over a plain vent hole. I admit that I am not clear about the matter and raise the point largely in the hope of getting it elucidated.

I should like to say a word on the subject of tandem wheels in undercarriages. There appears to be a certain amount of feeling that such arrangement is bad for turning on the ground, and that in turning heavy lateral loads are thrown upon the tyres and wheels. If the wheel base be kept short (meaning that if the tandem wheels be kept quite close together), and the wheel track be kept fairly wide (say at least twice the wheel base), I do not consider that the side loads set up on turning are of serious moment; our own trials of the gear on Braemar, including a lot of turning in quite small circles, have seemed to confirm this.

As regards Mr. North's point about the final extension of the Oleo leg of Braemar being not positive:—It is true that with no non-return valves, there would be a possibility of unequal lengths of leg should the machine have to alight

almost immediately after lifting; but I think there is little danger of this if valves be fitted, whilst the weight of a wheel, one half of an axle, etc., appears quite an effective positive force.

As regards the possibilities of solid or cushion tyres:—I am very anxious to see these tried, as their advantages are obvious. I appreciate that a certain amount of extra wheel weight might be necessary, but only experiment will determine if this be so, and if it be so whether the added weight will be of prohibitive amount.

As regards brakes:—Good results should be obtainable from the use of band brakes on the wheels, both for braking and steering. It seems quite time that this matter was tackled seriously. Probably the best way of actuating such brakes would be to have separate foot pedals (or separate hand levers on the control column) for the right and left-hand brakes (pedals for a multi-engine, hand levers for a single engine machine); with separate pedals (or levers) the machine could be braked, or turned, or both at once, and there would be no fear of imperfect compensation as with a coupled-up system.

As regards tail skids:—Braemar was designed at first with a sprung wheel tail support. But we feared that with this the machine would have run for ever, unless we fitted wheel brakes; so we reverted to a more orthodox shoe skid, as we did not feel justified at the time in experimenting with brakes.

REPLY TO DISCUSSION.

I have to thank Major-General Brooke-Popham for his kind appreciation of my paper. With reference to the point which he raises on the cushioning effect of planes near the ground, some tests were made in Messrs. Boulton and Paul's wind channel on a set of R.A.E. 15 biplane wings, the object being to determine the effect of ground interference on the "Bourges" biplane.

The results showed that the ground interference slightly increased the lift and decreased the drag for angles of incidence between 2 degrees and 12 degrees, approximately. For greater angles of incidence the drag increases and lift decreases.

The actual variations were such as to lead to the conclusion that the cushioning effect was negligible.

With regard to his suggestion that the method of winding affects the efficiency of the rubber shock-absorber, I agree that many forms of winding give rise to an irregular extension, with the result that the full amount of rubber is not uniformly brought into play.

Major Green has suggested that I put forward the independent frame and action of the Braemar Oleo Gear as being new; this was certainly not my intention, as I am very well acquainted with the R.E.7 Oleo gear, having been engaged on the production of that machine. I think that in the special paragraph in the Paper where reference is made to taxi-ing and periodic oscillating action, the distinction between the two functions of the landing gear is made clear.

Squadron-Leader Bramwell draws attention to the fact that a satisfactory undercarriage has a load factor of only 1.8; this seems very surprising, and I shall be exceedingly glad if further details are available for consideration. In any case, the shock-absorbing capacity of the gear should have been considerably improved by increasing the strength of the main struts.

The value taken for the density of the oil is certainly five per cent. too high. I do not think, however, this will have a great influence on calculations. With regard to the oil used—almost any form of oil is, I think, satisfactory, and it may be mixed with a little paraffin to avoid freezing. Although the viscosity of oil

changes rapidly with temperature, this has very little effect on the shock-absorbing capacity of the gear, the work done by the gear being principally that of accelerating the liquid through the orifices.

It is quite true that the shock-absorbing capacity of the gear would be affected if the oil froze solid; the same thing would apply to water.

Squadron-Leader Bramwell endorses the statement in the Paper with regard to interference resistance, and I am entirely in agreement with him as to the necessity of aeroplane designers having their own wind channels. Speaking from personal experience, one is certainly enabled to depart much further from one's immediate experience if a wind channel is available for obtaining quick results.

Major Grinsted refers to the results of tests on undercarriages carried out at Farnborough, and I hope that I shall some time have the opportunity of seeing details of the tests. The conclusion which he draws, viz., that undercarriages permitting a considerable amount of deflection have, *cet. par.*, greater shock absorbing capacity than those with small deflection, seems rather obvious.

With regard to the suggestion as to the flat winding of elastic, I suggest that the advantage obtained thereby is not due to the particular arrangement, *per se*, and that any arrangement of elastic permitting a certain deflection, and allowing the whole weight of the shock-absorbers to come into play will be equally satisfactory.

I have looked into a particular case of horizontal and vertical looping of the elastic, and as is of course necessarily the case, the energy absorbed is the same under each condition.

The maximum vertical load is, in the case of the flat elastic, some 15 per cent. less, but at the same time the deflection has increased to practically double. Any reduction of the vertical load from this arrangement is due entirely to the added deflection, and since the permissible deflection is usually one of the limiting features in the shock absorbing capacity of undercarriages, the actual advantage gained is not very apparent.

It is probable that in the tests the machines that had the flat winding actually took advantage of their maximum permissible deflection, and from this derived their superiority.

The statement that the divided axle type of Vee undercarriage appears more comfortable in landing and freer from breakage than the continuous single axle type seems to require further investigation. It is exceedingly difficult where tests are made on undercarriages having enormously varying characteristics, to define any one particular feature as definitely advantageous.

In reply to Captain Wilkinson, I am not aware of any side-load tests on tyres in which the platform is revolving to represent wheels in motion. It is quite probable, as he states, that the form of failure would be different from that shown, and indeed, experience has shown that tyres in actual practice stand up to much greater side loads than one would expect.

Mr. T. W. K. Clarke asks for information on the method of testing the tyres. The form of testing machines was shown in the illustrations, Figs. 12 and 13, in the lecture, a static load being applied to an axle passed through the hub. The method of determining deflection, etc., on the bouncing testing machine was described in the Paper.

With regard to taking u as $V \sin y$, Mr. Clarke prefers that the undercarriage should be considered as "just not collapsing." I do not consider there is any more justification for his proposal than for my suggestion that it should be considered as just collapsing; perhaps it would be more accurate to say that it is in a state somewhere between the two.

With regard to the possibility of designing for bigger values of u on large

machines, this is entirely due to the fact that the geometry of machines permits of greater absolute deflection in the undercarriage as the aeroplane increases in size. It is well known that it is possible to double the shock absorbing capacity of a landing gear by doubling the deflection. This is not accompanied by an increase of weight to the undercarriage in the same ratio, since the springs form a small proportion of the total weight of the gear. The same conditions, of course, apply to the Oleo gear. (Constructional difficulties usually limit deflection on small machines.)

With regard to lateral forces taken on the wheels and landing, these were touched on under the heading of "Landing on one wheel." It is possible to define the attitude in which the machine will land, producing side loads on the wheel, and this is mentioned in the Paper. It is customary to take the arbitrary load factor of two for this condition.

The value of the actual side force on the wheels under these conditions will vary very greatly according to the design of the machine.

I do not consider that we are, without further experimental evidence, in a position to discuss the question of side loads in any detail.

Mr. Clarke is quite right in supposing that, in accordance with the data available, the dynamic effect on the hysteresis of tyres and elastic is the opposite when compared with the static case.

With reference to his remarks on the coefficient Fl/m, Mr. Glauert has dealt with this during the discussion.

In reply to Mr. A. H. Tiltman, a part of the shock absorbing mechanism on the "Bourges" landing gear is pneumatic. I have done a certain amount of work on pneumatic shock-absorbers, but there is not room in this reply to the discussion to go into details. I am not prepared to positively accept the suggestion that pneumatic shock-absorbers would represent a saving in weight over an Oleo gear of the same shock absorbing capacity.

Mr. Pippard inquires further into the connection between $V \sin \gamma$ and u. I have not, I think, suggested that $V \sin \gamma$ is an appropriate value for u, but rather that it is an appropriate figure which may be obtained from any aeroplane for determining the value of u. Actually the value of $u = V \sin \gamma$ appears to represent the best undercarriage practice to-day, though, as I have already stated, I do not think it represents the best that can be done even now.

The suggestion that the undercarriage would just smash on striking the ground was intended as a definition of $V \sin \gamma$, rather than a suggestion that all the parts of the undercarriage, like the "wonderful one-horse shay" would, with one accord, disintegrate simultaneously.

I can heartily endorse Mr. Pippard's plea for a paper on "Seaplane Undercarriages," but I should imagine the subject would be much more complicated.

I am interested to note what Captain Barnwell tells us of his experience of using "I" section axles. He is correct in supposing that I was suggesting a box section capable of withstanding lateral loads. I should imagine that in the case of fairly long axles, such as the "Bourges," the saving might be as much as 50 per cent.

As Captain Barnwell says, where I mention rubber rings, I mean a ring of braid-covered cord, not a ring of bare rubber.

With regard to the fitting of a relief valve in the Oleo gear, this is designed to open at some period where the loads on the undercarriage will be approaching the maximum which it can withstand. If no relief valve is fitted, there is a definite maximum vertical velocity which must break the undercarriage instantly

every time it lands. I am afraid it is rather difficult to go with much further detail into the matter now, but if Captain Barnwell works out a particular case I am sure he will find the advantage derived from the valve.

My suggestion with regard to positive extensions of the Oleo leg arose out of the experience with other Oleo gears which were fitted with fairings, and I think it is quite possible that their tendency to stick up was largely due to friction in the fairings.

I think at a guess I should be inclined to put the weight of the wheels with solid tyres at approximately double that of the pneumatic tyred wheel; and if anything, I think this is on the low side.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

SIR,—The AERONAUTICAL JOURNAL for December, 1919, contains an article by Sir Horace Darwin, F.R.S., on "The Static Head Turn Indicator for Aeroplanes," in the course of which (pages 623 and 624) he gives two alternative explanations of the action of this turn indicator on a properly banked turn. On page 624, line 16, the following words occur:—"Although these two ways of considering the forces which act on the air in the tube are so different, they are both correct." It is true that the *result* obtained by each method of attack is the same, but as the writer has found some of the statements difficult to follow the following comments may be useful:—

(i) On page 623, fourth line from bottom, we have:—"1. As the banking is at the correct angle the resultant of gravity and centrifugal force acts at right angles to the direction of the tube and has no effect."

(ii) On page 624, dealing with the action of gravity from the second point of view (seventh line from top) occur the words:—"1. Gravity acting on the air in the tube. As the tube is banked this will tend to make the air flow inwards," *i.e.*, down the tube.

(iii) Again, on page 624, top, we have:—"3. The atmospheric pressure at the two static heads is not equal; as the aeroplane is banked, the outer end is higher up, and at a place where the air is at a less pressure. The differential manometer will show this difference of pressure." On page 624, line 9, the statement about inequality of atmospheric pressure is repeated with the remark that its effect on the manometer is "obviously equal and . . . opposite" to the tendency of the air in the tube to flow inward, due to the action of gravity.

The writer believes that students will find difficulty in obtaining a clear idea of the principle on which the action of the valuable instrument described by Sir Horace is based, and suggests the following method of procedure.

The action of *gravity* on the turn indicator may be examined by considering a tube open at each end and fitted at the middle of length with a flexible diaphragm, whose deflection may be taken to indicate a difference of pressure between its two sides. Suppose this tube at rest and supported with its long axis horizontal and in a horizontal plane where the atmospheric pressure is A. This pressure is the result of the action of gravity on the whole of the atmosphere from the ground upwards, and is assumed to be uniform over that plane so that there will be no deflection of the diaphragm. Now imagine the axis of the tube vertical and the diaphragm in the same horizontal plane as before; the upper extremity will be at a lower pressure and the lower one at a higher pressure than before, due to the pressure gradient in the atmosphere caused by the action of gravity; but there will be no pressure difference at the diaphragm, since the pressure gradient inside the tube will be the same as outside, and the pressure on either side of the diaphragm will be A as before. The same is true for any inclined position of the tube; for any vertical displacement the pressure difference will remain zero though the absolute value of the pressure is changed.

If the ends of the tube are now connected to static heads the arrangement will be analogous to the turn indicator on an aeroplane. The result of connecting this hypothetical tube to static heads is to render the pressure in it independent of steady motion along a straight path, for as the name implies, these heads should be so designed that the pressure in them is always equal to the true or static pressure.

We may now say, therefore, that the turn indicator will not be affected by differences of air pressure due to the action of gravity or to the angle of bank.

The reading of the indicator will depend on the centrifugal force as explained by Sir Horace on page 624.

The statement on page 618 that "inequality of pressure is because it is impossible to make both static heads absolutely similar" does not accord with the writer's experience. The calibration of a static head of N.P.L. form on the whirling arm at the Laboratory* showed it to read the true pressure to within one-tenth of one per cent., which was the order of accuracy of the experiment, and later calibration of various forms of head shows that considerable modification in design is permissible if certain simple precautions are observed. It is probable that in ordinary use the static tube reads the true pressure to an order of accuracy higher than that of present methods of measurement.

Finally, on page 623, line 18, occurs "*Pitot tubes* (the italics are the present writer's) for this reason also, are better than Venturi tubes." Since pitot tubes cannot be used for turn indicators this is presumably an error for "*static tubes.*"

Yours faithfully,

J. R. PANNELL.

To the Editor of the AERONAUTICAL JOURNAL.

DEAR SIR,—I thank Mr. J. R. Pannell for pointing out that at the end of my paper on "The Static Head Turn Indicator" the words "pitot tubes" is an error. The comparison should be between Venturi tubes and static openings and not between Venturi tubes and pitot tubes.

Mr. J. R. Pannell's opinion on the accuracy of static openings can undoubtedly be taken as final, and it is satisfactory to know that considerable differences of form do not cause much error if certain simple precautions are observed. It is pointed out in my paper that when flying near the ground at 80 miles per hour in a circle of one mile radius, that the banking angle is 4deg. 10min., and the difference of pressures is about 1mm. head of water. This is about 1/10,000 of atmospheric pressure or ten times the accuracy given by Mr. J. R. Pannell. If the flight is at a great height the difference of pressures may be half this amount, or 20 times the accuracy given. Mr. J. R. Pannell says: "It is probable that in ordinary use the static tube reads the true pressure to an order of accuracy higher than that of present methods of measurement." From this it would seem that a more refined method of measurement is required for testing this point when static openings are used for the special purpose of the turn indicator.

The explanation of the action of the turn indicator given by Mr. Pannell seems to me to be perfectly clear and most easy to understand.

Yours faithfully,

HORACE DARWIN.

The Orchard, Huntingdon Road,
Cambridge, January 18, 1920.

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* Report of the Advisory Committee for Aeronautics, 1912-13, p. 35.

REVIEWS.

Aircraft in Peace and Law. J. M. Spaight. MacMillan. 8s. 6d. net.

An aeroplane is forced to land, on account of engine trouble, in a field of standing corn. Can the farmer claim damages? If so, does he claim from (1) the pilot, (2) the owner of the aeroplane, (3) the maker of the engine, (4) or the Government?

Mr. Spaight, in his admirable and much needed book, lays down the difficulty of the solution of such a problem and he puts forward a number of proposals which should indicate the line of thought of lawyers of the future. Probably the most practical of these proposals is one based on a suggestion of Professor Sperl, who says:—"No aircraft will be allowed to make an ascent until it has been registered, and the formality of registration will be linked with the obligation of the proprietor to enrol himself as a member of an Aeronautical Society. All the societies will levy subscriptions; there will thus be established, in each state, funds of indemnity and insurance. They will enter into relations with one another and will apportion the charges for damages among all the associations, in one central office for the world. The question of the aeronaut's culpability will be absolutely immaterial in relation to the victim's claim and the civil procedure necessary. It will be sufficient to prove that the damage has been caused by some act connected with the aeronaut's flight. The culpability of the aeronaut will eventually be taken into account only as a domestic matter arising between the aeronaut and the society of which he is a member."

Another little problem of the aerial age is put forward by Mr. Spaight as follows:—"Suppose a crime is committeed in a German aircraft over French territory, and committed in circumstances which involve disturbance of public order, and that consequently it falls under French legislation and jurisdiction. After the machine lands in Germany will the German Government be requested and expected to hand over to France the authors of the crime?"

Some countries think not and others the reverse. Mr. Spaight wisely leaves the question to be answered by the reader. The book, however, abounds in suggestions for the solutions of aerial problems which are now rapidly becoming urgent, and contains many authoritative quotations from the leading legal authorities in the world. It is a book which must prove of the greatest value to those who are called upon to lay down and carry out the laws of the air.

J. L. P.

The Aviation Pocket Book, 1919-20. R. Borlase Matthews. 12s. 6d. net. Crosby, Lockwood and Co.

Mr. Borlase Matthews is to be congratulated upon bringing out the new edition of his well-known pocket book in the form he has. He has not only improved it beyond all recognition, both in the way in which it has been arranged and classified, but also in the amount of up-to-date aeronautical data which he has managed to include. No aeronautical pocket book for the next year or so can possibly hope to cope with the overwhelming flood of new facts, figures and experiments which has poured forth in a disorderly torrent since the signing of the Armistice, but Mr. Borlase Matthews has made an extremely creditable effort to stem that torrent and has reduced a great amount of order out of a still greater amount of chaos.

"The Aviation Pocket Book for 1919-20" avoids a number of pitfalls which the compiler of almost every pocket book cheerfully falls into. Mr. Matthews steers clear of the endless conversion tables which nauseate and do not nourish

the brains of the engineer and replaces them by tables of conversion constants which are infinitely more useful.

There are a number of extremely useful tables for the designer, notably tables giving resistance coefficients of various bodies; tables of weight estimates for preliminary design; wire rope and streamline wire strengths; and moments of inertia of standard steel tubes among others. Mr. Matthews leaves out an extremely important set of figures, and it is rather puzzling to know why they have been omitted. These are tables giving the centre of pressure coefficients and lift and drag and moment coefficients for standard aerofoils. The dimensions of well known aerofoils are given, but they are, naturally, useless without their aerodynamic data.

On page 105 there is a misprint, an important one, in the formula for a strut under a lateral bending moment. The quantity in the bracket should read $P_e/(P_e - P)$ and not $(P_e - P)/P$ Mr. Matthews might, too, explain a little more exactly what he means by the formula, and the danger of using it to find the factor of loading of an aeroplane spar. One might ask him, for example, what does he mean by l?

On page 112 a curve is given showing the strength of tapered struts. This curve should, first of all, be acknowledged to Mr. Arthur Berry, to whom it is due, and secondly, attention should be called to the fact that it is a curve for *elliptically* tapered struts. The curve, too, conveys nothing to the intelligent engineer, for it gives the strength of some unknown type of tapered strut in terms of " percentage strength "—of what?

The bibliography is not up to the general standard of the rest of Mr. Matthews' book. It contains a number of books of a distinctly rubbishy nature, and it contains a number of good ones. As Mr. Matthews carefully comments on some he might point out those which are either worth buying or not, or omit criticism altogether. Criticism is not a function of a pocket book so much as selection.

" The Aviation Pocket Book " strikes a new, and to the reviewer a distinctly refreshing note in the way it is produced such that any leaf may be removed and inserted in the owner's own private pocket book. This should be a useful asset to the book.

The introduction of the well-known decimal system of classification is one which is of doubtful value. However, whatever the demerits of the book are, they are completely outweighed by the merits. It is a pocket book which should be in every aeronautical engineer's drawing office.

J. L. P.